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TWCP ELECTRON BEAM TESTING PROGRAM

Volume I - Summary

Effects Technology, Inc.
5383 Hollister Avenue
Santa Barbara, California 93111

5 April 1979

Final Report for Period July 1977—December 1978

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Volume I of four volumes. Summarizes the results of a series of electron beam tests that: (1) characterized the Maxwell Laboratory's Blackjack III pulsed electron beam facility for material response studies related to nuclear weapons effects on reentry vehicle heat-shield materials; (2) developed a set of instrumentation to diagnose the electron beam environment and measure material response as to impulse and stress generation; and (3) generate impulse and stress data on FM5822A carbon phenolic and 91-LD phenolic		

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Depth-Dose Measurements

20. ABSTRACT (Continued)

resin materials. The data generated demonstrated the utility of the Blackjack III facility and will be used in a separate program entitled, "TWCP Correlation Program." The instrumentation developed are applicable to these types of tests on a variety of facilities. The environmental diagnostical instrumentation achieved a significant reduction in experimental uncertainties when compared to prior techniques. This program was conducted within the framework of the Nuclear Hardness Evaluation Procedures Program and the concepts developed therein.



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SUMMARY

This report describes a series of pulsed electron beam machine experiments performed at the Maxwell Laboratories Blackjack III facility. Both impulse and particle velocity vs. time measurements were made on 91-LD phenolic resin, manufactured by Ironsides Chemical, and type FM-5822A tape wrapped carbon phenolic (TWCP) manufactured by HITCO.

This program was funded under Defense Nuclear Agency contract DNA 001-78-C-0063. The COR was Mr. Don Kohler, and the period of performance was July 1977 to December 1978.

This is the first volume of a four volume set describing the electron beam tests in support of the TWCP Correlation Program. The four volumes are:

TWCP Electron Beam Testing Program:
Volume I - Summary A086211

TWCP Electron Beam Testing Program:
Volume II - Preliminary Characterization of the
Blackjack II Pulsed Electron Beam for Material
Response Studies

TWCP Electron Beam Testing Program:
Volume III - Material Response Instrumentation for
the Blackjack III Pulsed Electron Beam Facility

TWCP Electron Beam Testing Program:
Volume IV - Electron Beam Tests in Support of the
TWCP Correlation Program A086214

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PREFACE

The successful completion of this program required the cooperation of a number of individuals both in the government and industry. Such cooperative efforts have and continue to be a significant reason why the Nuclear Hardness Evaluation Procedures (NHEP) Program, and related efforts such as this one, have been successful and productive. In addition to this cooperation, the success of any program relies heavily on the capabilities of those performing and directing the work. The compiler and editor of this report, and author of Volume I, was not directly involved in the test series themselves. The individuals who did directly contribute to the test series and overall program content through numerous meetings, late evening discussions, calculations and experiments deserve the credit for the results of this program.

These individuals include:

Don Kohler, Headquarters Defense Nuclear Agency (DNA) -
For sponsoring and directing the program, and his encouragement to the various participants;

Dale Schallhorn, Harry Diamond Laboratory (HDL) - As
the on-site experiment consultant. His expertise and experience in electron beam testing were very important contributions to the successful completion of this program. This included many fruitful discussions and on-site assistance;

Dave Newlander, Air Force Weapons Laboratory (AFWL) -
For technical support on the theoretical and computational aspects of the program and assistance in coordinating the various participants;

Marty Rosen, Effects Technology, Inc. (ETI) - For the overall technical guidance and expertise that led to a definition of the test program as to the types of experiments and general configurations of the instrumentation;

Nils Froula, Corrales Applied Physics Co. (CAPCO) - For translating the instrumentation requirements into hardware and performing the experiments. Volumes II, III, and IV of this report were authored by CAPCO under subcontract to ETI;

Maxwell Laboratories - For the crew who ran the machine, as well as the beam physicists who designed and built the machine hardware. Their efforts led to the final configuration that was successful for material response studies on Blackjack III.

To all these, and others unnamed, acknowledgement is given for completing a difficult task - establishing a major new material response simulation facility and successfully obtaining material response data in a high energy, pulsed electron beam facility.

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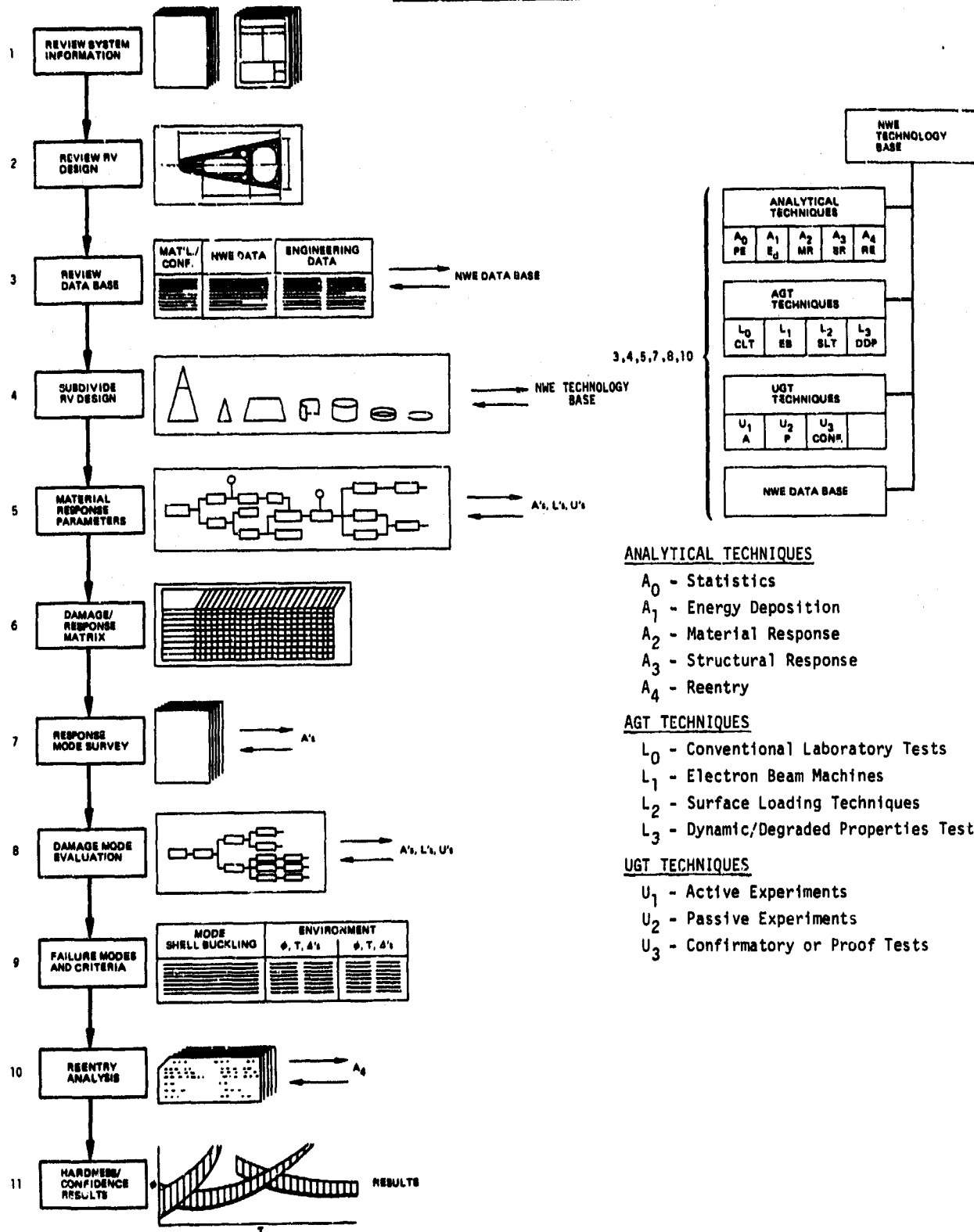
1.0 INTRODUCTION

This report describes the experiments performed, and the results obtained during testing performed from July 1977 to July 1978 using the Blackjack III (BJIII) pulsed electron beam machine at Maxwell Laboratories. The materials tested under this effort were 91-LD phenolic resin, manufactured by Ironsides Chemical, and type FM-5822A tape wrapped carbon phenolic (TWCP), manufactured by HITCO.

The basis for this program was derived from the Nuclear Hardness Evaluation Procedures (NHEP) Program, also sponsored by DNA. A crucial question raised within NHEP was the utility of electron beam data for performing hardness assessments of reentry vehicles. This requires that the results of an experiment and/or analysis be relatable to reentry vehicle performance as displayed in fluence-temperature space. When this criterion is met, the parameters measured are critical to a hardness assessment, and the techniques used to ascertain that parameter are sufficiently accurate to prevent the assessment from being dominated by uncertainties; i.e., the experiment and/or analysis should decrease the uncertainties, and also have an influence on the performance curves.

To meet these objectives, it is necessary to use the NHEP Methodology Overview flowchart, shown in Figure 1.1, as a reference. From the flowchart, the pertinent portions

NHEP METHODOLOGY OVERVIEW



ANALYTICAL TECHNIQUES

- A₀ - Statistics
- A₁ - Energy Deposition
- A₂ - Material Response
- A₃ - Structural Response
- A₄ - Reentry

AGT TECHNIQUES

- L₀ - Conventional Laboratory Tests
- L₁ - Electron Beam Machines
- L₂ - Surface Loading Techniques
- L₃ - Dynamic/Degraded Properties Tests

UGT TECHNIQUES

- U₁ - Active Experiments
- U₂ - Passive Experiments
- U₃ - Confirmatory or Proof Tests

Figure 1.1 NHEP Methodology Overview Flowchart.

of the Nuclear Weapons Effects (NWE) Technology Base for the determination of material response parameters (i.e., impulse and stress generation as a function of fluence)

- NWE Data Base
- A_0 - Statistical Analytical Techniques
- A_1 - Energy Deposition Analytical Techniques
- A_2 - Material Response Analytical Techniques
- L_0 - Conventional Laboratory Testing Techniques
- L_1 - Electron Beam Testing Techniques
- L_3 - Dynamic/Degraded Properties Laboratory Techniques

The first five - NWE Data Base, A_0 , A_1 , A_2 and L_0 - provide information and tools for analyzing data that are generated in the electron beam environment, L_1 . L_3 is a relatively new technique for NWE studies, and refers to the use of physical chemistry and thermodynamics as a complement to electron beam techniques.

L_1 , the electron beam test technique, is vitally important to the determination of impulse-fluence relationships because no other aboveground test technique has been identified that can achieve rapid, in-depth energy deposition in such a manner as to provide useful information. Other techniques have been tried and have been found to provide insufficient information when compared to the electron beam technique.

However, since the history of high energy pulsed electron beam machine performance has sometimes been one of uncertainty, unreliability and nonrepeatability, this program was designed

to attempt to overcome these prior difficulties through careful planning and innovative instrumentation techniques. This report provides an overview of these techniques, and a preliminary analysis of the data obtained with particular emphasis on experimental uncertainties. Volumes II through IV, prepared by CAPCo as subcontractors to ETI, contain the experiment and instrumentation specifics. The data correlation with analytical techniques is currently underway in a separate program entitled "TWCP Correlation Study Program", Air Force Weapons Laboratory Contract F29601-77-C-0076.

This report is divided into four volumes:

- Volume I - Summary
- Volume II - Preliminary Characterization of the Blackjack III Pulsed Electron Beam for Material Response Studies
- Volume III - Material Response Instrumentation for the Blackjack III Pulsed Electron Beam Facility
- Volume IV - Electron Beam Tests in Support of the TWCP Correlation Program.

Volume I summarizes the results from six separate test series performed at the Maxwell Laboratory's BJIII facility. Volumes II, III and IV are reports documenting each of the test activities in detail.

Sections 2.0, 3.0 and 4.0 of this volume summarize the Test Objectives, within the NHEP context, the instrumentation used to diagnose the electron beam environment as well as measure specimen response, and describe the data

tests. Section 5.0 describes the treatment of the data in some detail to arrive at preliminary results as to test uncertainties and implications, which are reported in Section 6.0.

2.0 TEST OBJECTIVES

To demonstrate the utility of pulsed electron beam machine data within the NHEP context, it was necessary to define four objectives, which were met sequentially in time:

- Define the test conditions available in the Black-jack III machine through fluence and depth-dose diagnostical techniques;
- Design and evaluate instrumentation techniques compatible with the BJIII radiation, electromagnetic and mechanical shock environments;
- Generate a set of data useful for correlation with material response analytic techniques;
- Examine the uncertainties of the data generated.

The first objective was partially addressed in the first test series conducted under contract DNA001-76-C-0357 in July 1977. That test series demonstrated the overall feasibility of using the BJIII electron beam machine for future material response experiments. Preliminary beam characterization was performed in that early test series, and this characterization was completed prior to data acquisition under contract DNA001-78-C-0063.

The second objective was to develop instrumentation that was capable of diagnosing the beam during data pulses,

and also to measure material response. These instruments were to reduce uncertainties experienced in other electron beam test programs, if possible, while operating in the extremely hostile electron beam environment. Specifically, all instruments had to operate in the presence of intense ionizing radiation, high pulsed and steady state electromagnetic fields and mechanical shock generated when the machine is fired. All of these conditions were met by the set of instruments developed.

The third objective was to provide material response data. The particular response parameters of interest to the analytical efforts include the energy dependent Grüneisen parameter $\Gamma(E)$ and the energy dependent final or "sublimation" energy $E_s(E)$.

The Grüneisen parameter, defined as

$$\Gamma(E) = \frac{P}{\rho E}$$

where

$P \equiv$ hydrostatic pressure generated

$\rho \equiv$ material density prior to energy deposition

$E \equiv$ energy deposited per unit mass

and the energy is deposited in a sufficiently short time for a constant volume process. The pulse duration of the BJ III machine is sufficiently long that a constant volume condition is not achieved. Hence, the measured parameter is usually called the "effective" Grüneisen.

The final energy, $E_s(E)$, is defined in terms of the energy within an expanding vapor cloud that is generated when sufficient energy is deposited in the material to cause phase changes. When this energy is rapidly deposited, in times on the order of tens of nanoseconds, the vapor cloud rapidly expands away from any remaining solid material. The $E_s(E)$ is then the energy within the vapor unavailable for producing work during adiabatic expansion

$$\int_{V_0}^{\infty} PdV = E - E_s(E)$$

where E is the energy deposited in the vaporized material and $\int PdV$ is the energy released during expansion from an initial volume V_0 to infinite volume (zero temperature). $E_s(E)$ can be characterized as the energy used in irreversible processes such as the breaking of chemical bonds.

To determine these functions, particular parameters are measured in experiments. To determine $\Gamma(E)$, pressure was not measured directly in this program. Rather a laser interferometer was used to measure rear surface particle velocity, which is related to $\Gamma(E)$. To determine $E_s(E)$, the relatable parameter is impulse generation in a sample due to the forces produced by an explosively generated vapor cloud. This imparted momentum can be analytically related to $E_s(E)$ through calculations performed by hydrodynamic computer code models which solve the Lagrangian

equations of motion in matter. For this program three linear translation impulse gages were developed and used.

The fourth objective was accomplished by statistically treating the data generated in this program, particularly the impulse-fluence relationships, and through comparisons with data reported in Reference 1.

This set of program objectives was derived through the application of the NHEP Methodology, starting with the overview chart shown in Figure 1.1, and concluding with the more detailed flowchart for electron beam testing, L_1 , shown in Figure 2.1. It was through this approach that program success was achieved.

3.0 BEAM CHARACTERIZATION AND INSTRUMENTATION DEVELOPMENT

Electron beam characterization and material response instrumentation development were accomplished during four test series:

Test Series I: 11 to 22 July 1977

Test Series II: 15 to 23 September 1977

Test Series VI: 1 to 7 December 1977

Test Series IV: 27 January to 2 February 1978.

Table 3.1 summarizes the primary activities for each of these test series.

Section 3.1 summarizes the BJ III test environment characterization; Section 3.2 the impulse gage development; and Section 3.3 the interferometry measurements. Volumes II, III and IV of this report provide the basis for these summaries.

3.1 ELECTRON BEAM CHARACTERIZATION

Determination of the BJ III electron beam environments was initially performed in Test Series I and II. The two objectives of these series were to improve the beam uniformity and to define the machine parameters which would provide a high fluence, 300-cal/cm^2 , test configuration. The experiment configuration is shown in Figure 3.1. Cathode shaping experiments, which included varying the edge curvature, disk angle and diameter, were performed to study the effect on beam uniformity. These tests used the diagnostic calorimetry described in Volumes II and III. The fluence distribution was charted in detail for a target position 65-cm from the anode.

Table 3.1

SUMMARY OF ACTIVITIES

<u>Test Series</u>	<u>Shot No.</u>	<u>Beam Related Developments</u>	<u>Response Instrumentation Developments</u>
I	1574-1651	<ol style="list-style-type: none"> 1. Beam utilization feasibility study. 2. Preliminary characterization of BJ III beam. 	<ol style="list-style-type: none"> 1. Beam diagnostics
II	1700-1748	<ol style="list-style-type: none"> 1. Attempts to improve gross beam uniformity. 2. Attempt to establish high fluence station. 3. First encounter (last half of series) with series diode flash-over on BJ III. 	<ol style="list-style-type: none"> 1. Check inertial isolation scheme. 2. Measure drift tube displacement. 3. Check noise in photomultipliers. 4. Proof test with prototype optical image gauge.
III	1778-1808	<ol style="list-style-type: none"> 1. Diode flash-over observed in 30% of tests. 2. Peak diode voltage reduced to 850 kV for AFWL CP tests. 	<ol style="list-style-type: none"> 1. Check effect of magnetic fields on laser. 2. Debug dual impulse impulse gauge. 3. Set up instrumentation table.
IV	1962-1942	<ol style="list-style-type: none"> 1. 1 MV peak diode voltage achieved consistently with new diode insulator. 2. Detailed mapping of drift tube field. 	<ol style="list-style-type: none"> 1. Interferometer check out shots. 2. Rebuild table.

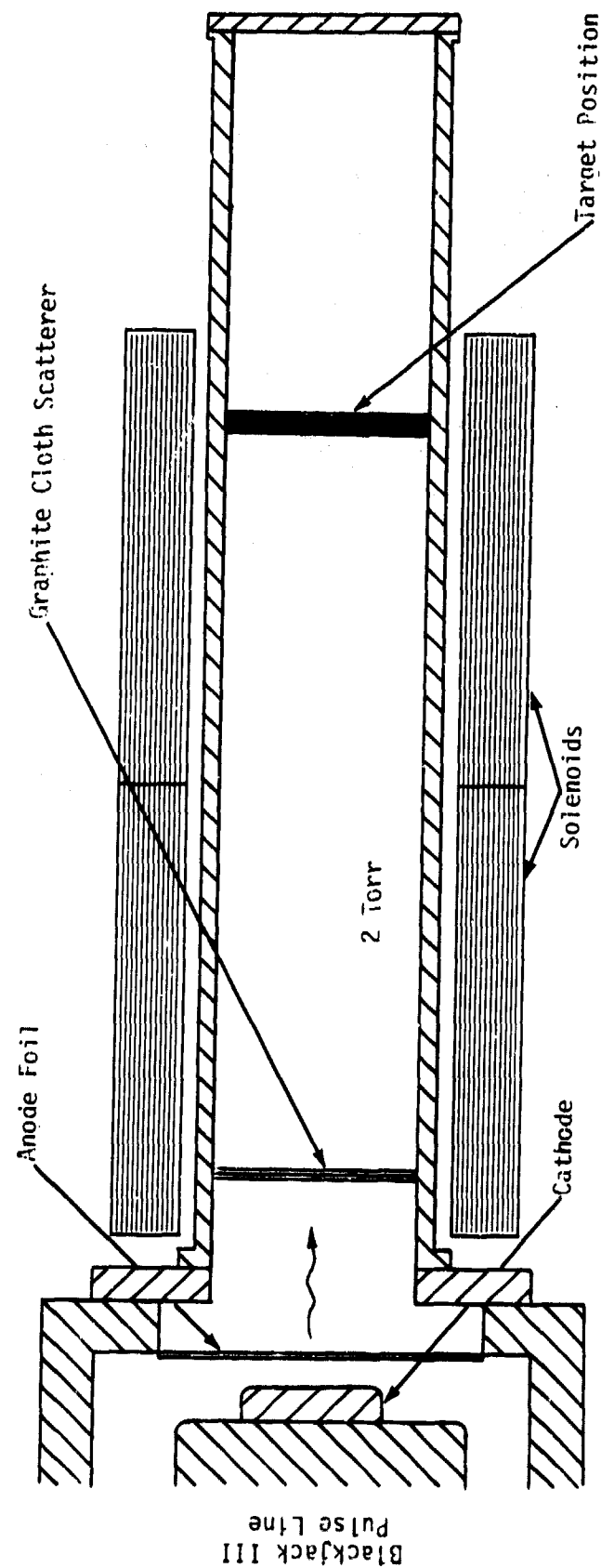


Figure 3.1 Experiment Configuration

A few experiments were performed by modifying the conductive guide cone with the intent of improving beam transport efficiency and thereby uniformity. These attempts led to no improvement in beam uniformity over that observed in the July 1977 test series, and, in fact, the uniformity and repeatability were degraded. The attempts to define machine parameters for achieving a 200-cal/cm^2 test environment were also fruitless. It was found that when this fluence was attained, the exposure area was too small for meaningful material response testing. At this 55-cm station, higher than anticipated doses were found which fractured calorimetry elements, thus precluding accurate fluence measurements and indicating a higher dose-to-fluence ratio than that expected based on pretest analysis.

These results were attributed to anomalous behavior of the axial magnetic guide field. Figure 3.2 shows the relative field intensity as a function of position. The pretest curve includes estimates of eddy currents induced in the diode door. This prediction was checked in Test Series II, and is also shown in the figure. For the positions where data were taken, the calculations are in substantial agreement with measurement. However, with the occurrence of anomalously high doses for targets placed at distances less than 55-cm from the anode, it was decided to map the magnetic field in detail. The results, shown in Figure 3.2, indicate a significant departure from predictions. The maximum field

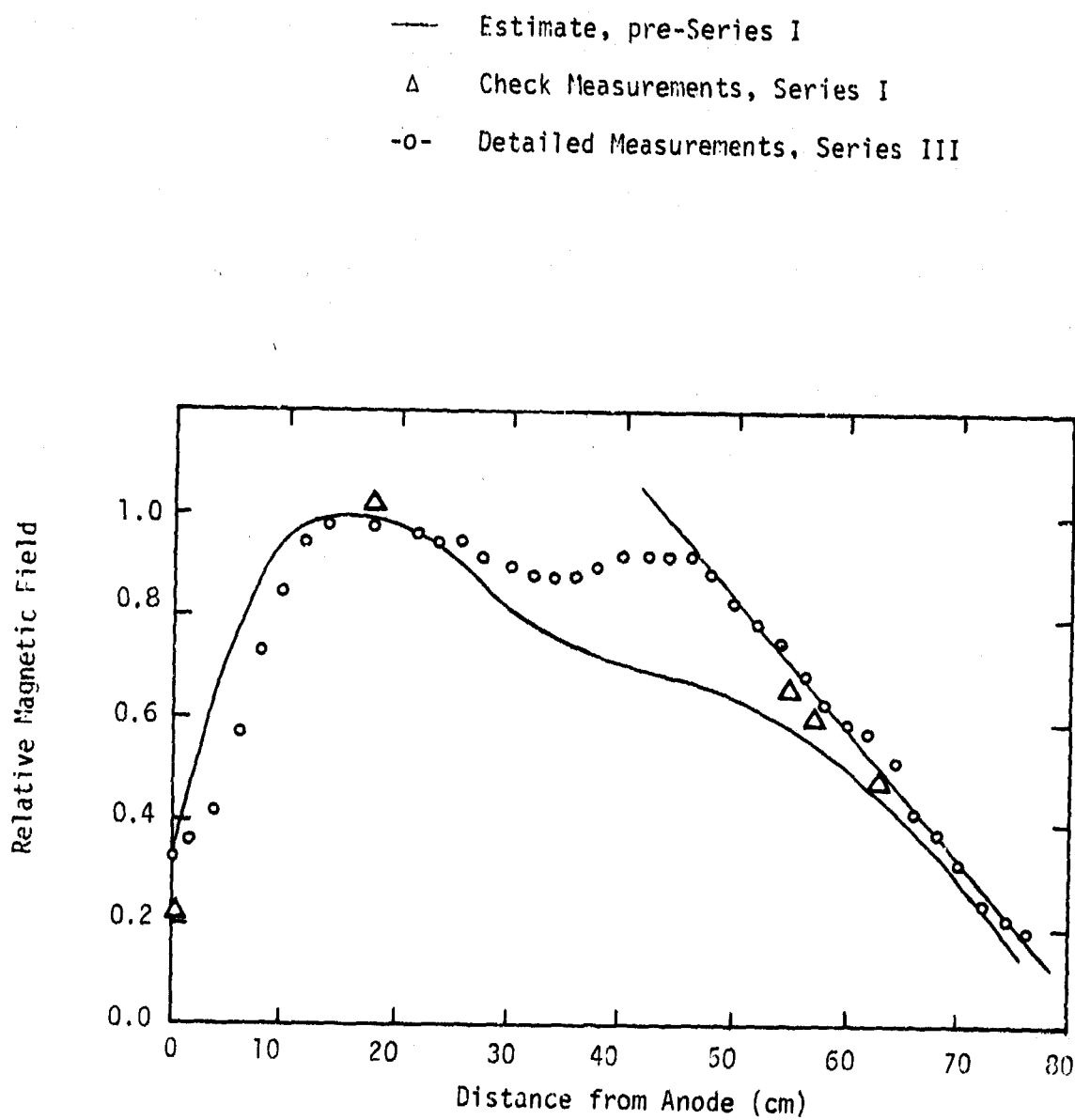


Figure 3.2 Electron Guiding Axial Magnetic Field

field strength was found at 15-cm with an intensity of 25-kG. This mapping of the magnetic field also aided in the determination of energy deposition in the test materials. According to the adiabatic expansion theory in Reference 2, electron fluence is proportional to field intensity. The data points shown in Figure 3.3 are representative of this theory, and of the well behaved 1-MV beam conditions of July 1977 and January 1978. The theory also provides a method of calculating the maximum electron precession angle, θ_{\max} as a function of field strength

$$\theta_{\max} = \sin^{-1} B^{1/2}$$

and thus as a function of position, as seen in Figure 3.4. From assumptions about electron distributions at the cathode, the point of electron injection into the magnetic field, the mean electron angle can be calculated as a function of axial position. This in turn allows for the calculation of peak dose for given spectra using a Monte Carlo electron transport code. An example of such calculations as a function of axial position is shown in Figure 3.5 for a typical 1-MV peak voltage BJ III spectrum. Such curves are typically used in pretest experiment design. Variation in the magnetic field can be obtained by varying the current into, and the relative position of, the second solenoid as shown by the dashed lines in Figure 3.5. By such variations one can in principle reduce the dose-distance gradient and thereby improve the repeatability of fluence.

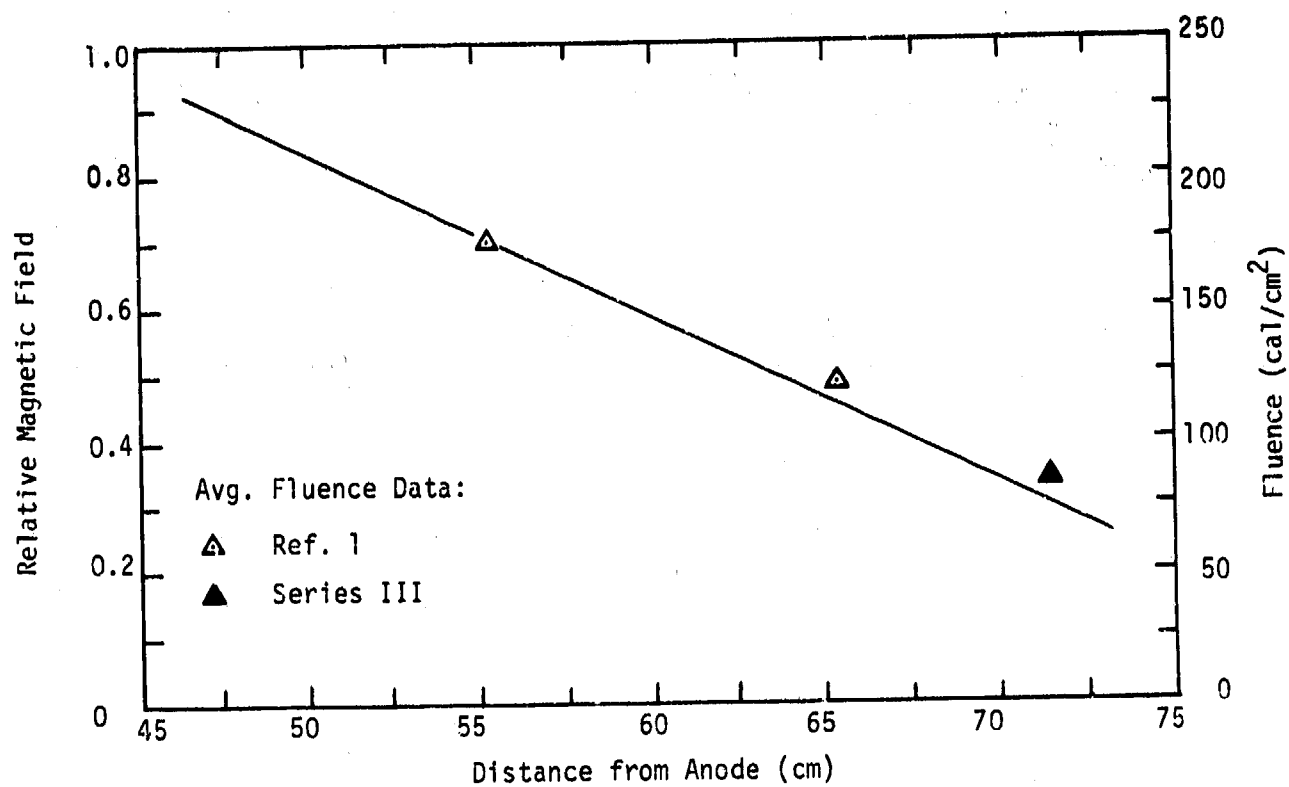


Figure 3.3 Correlation between Measured Field and Measured Fluence

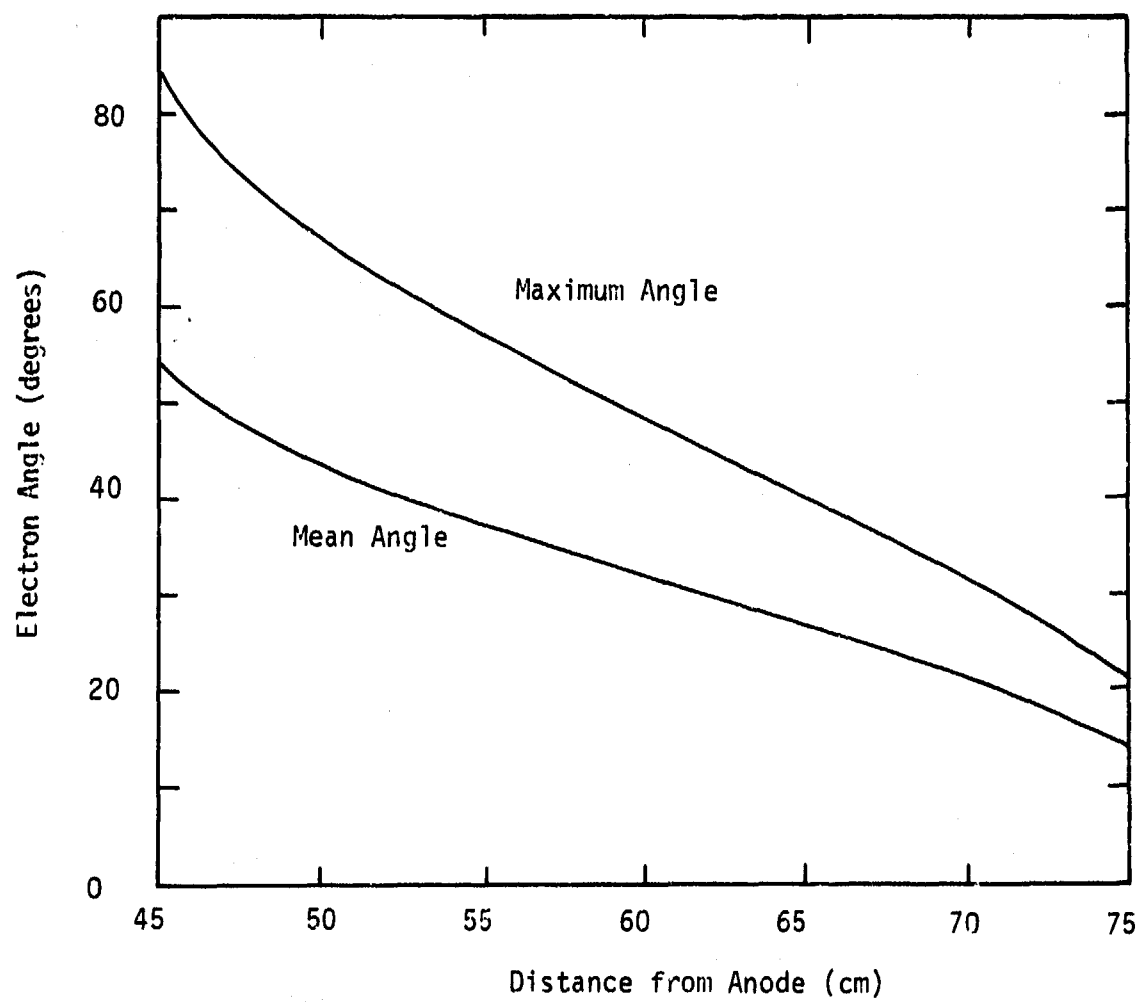


Figure 3.4 Calculated Electron Angles

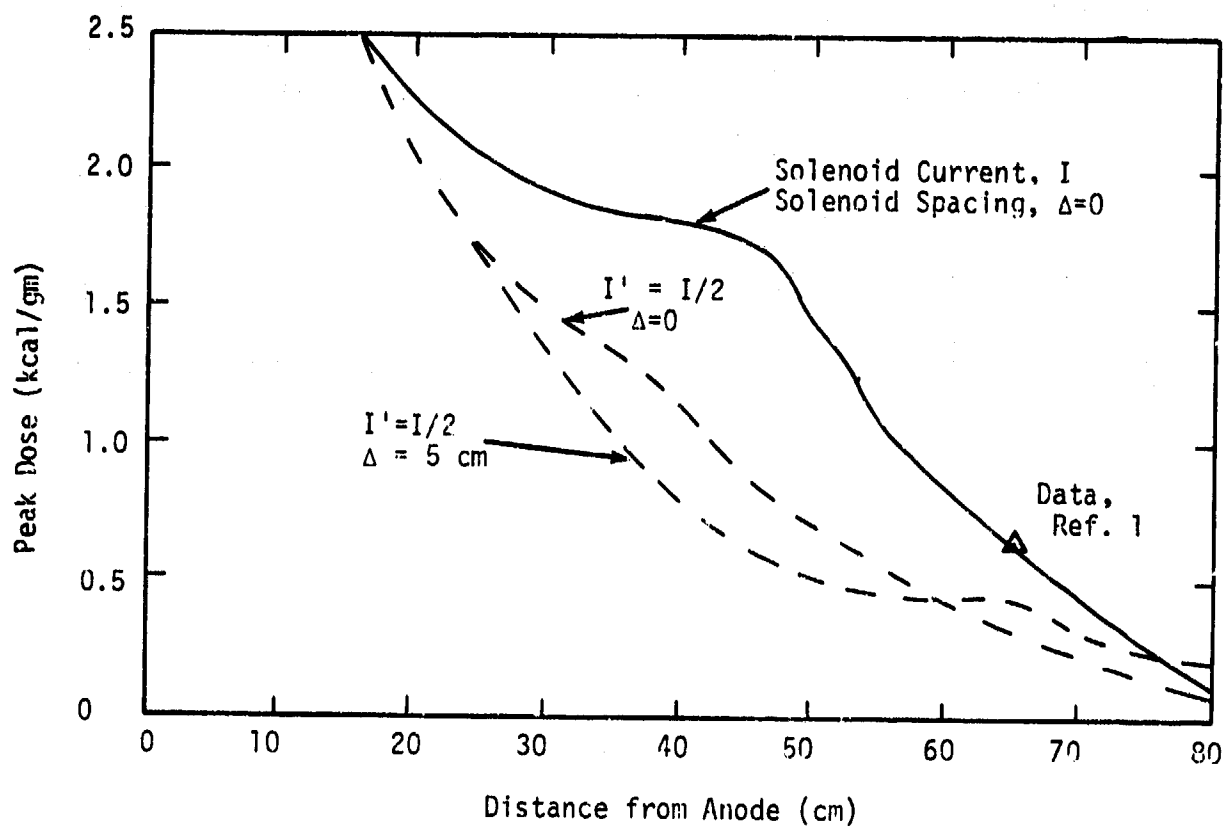


Figure 3.5 Peak Dose Versus Distance from Anode

During Test Series II, 45 shots were fired. Only once during the first 23 pulses did flash-over (dielectric breakdown) occur. However, during the subsequent 22 pulses, 12 flash-over events were noted at both early and at late times. These events occurred in almost every shot where the peak diode voltage exceeded 700-kV. This problem was serious enough to require that the diode impedance be reduced for the final 12 pulses in order to assure completion of the required instrumentation development tests. The average impedance was changed from 1.7-ohms to 1-ohm to accomplish this purpose.

Test Series III consisted of 31 pulsings. Ten of the 31 shots exhibited flash-over, leading to the conclusion that a peak accelerating voltage of 1-MV was unachievable with the existing diode insulator. The impedance was again reduced near the end of this series to prevent flash-over. This change yielded an average peak diode voltage of 850-kV for the remainder of the series.

Test Series IV was comprised of 16 pulsings. A new diode insulator had just been installed by Maxwell Laboratories, and one of the purposes of this short test series was to evaluate the effects of this equipment change. As was anticipated, high peak diode voltage was consistently achieved in each of these 16 tests.

3.2 IMPULSE GAGE DEVELOPMENT

During the course of this program, three impulse gages were designed which provided accurate data in the electron

beam environment. In addition to having to perform in the intense electromagnetic and radiation fields associated with this environment, they also had to operate within, and not perturb, the magnetic guidance field. Displacement of the entire drift tube due to shock effects from machine discharge required that the impulse measurement system be decoupled from the machine.

To cope with the magnetic field problem, the impulse gages were all constructed of nonmagnetic materials, and any required conducting materials were maintained at a minimum thickness such that no significant forces resulted from the 36-Hz, 25-kG magnetic guide field. The adequacy of these precautions was verified by testing the assemblies in the pulsed field without firing the electron beam machine.

Measurements of displacements of the drift tube assembly during beam pulsing were made using two different measurement techniques. The results, shown in Figure 3.6, indicated that no measurable motion occurred prior to about 5-msec. This time set the maximum undisturbed read time for any impulse gage. As a result of these measurements, a shock isolation vacuum coupling was fabricated using a rubber boot. Figure 3.7 shows this system, which provides for a quick disconnect vacuum flange while allowing for several centimeters of relative motion.

A separate impulse gage was developed for each of the three test series. The first to be tested is shown in Figure 3.8.

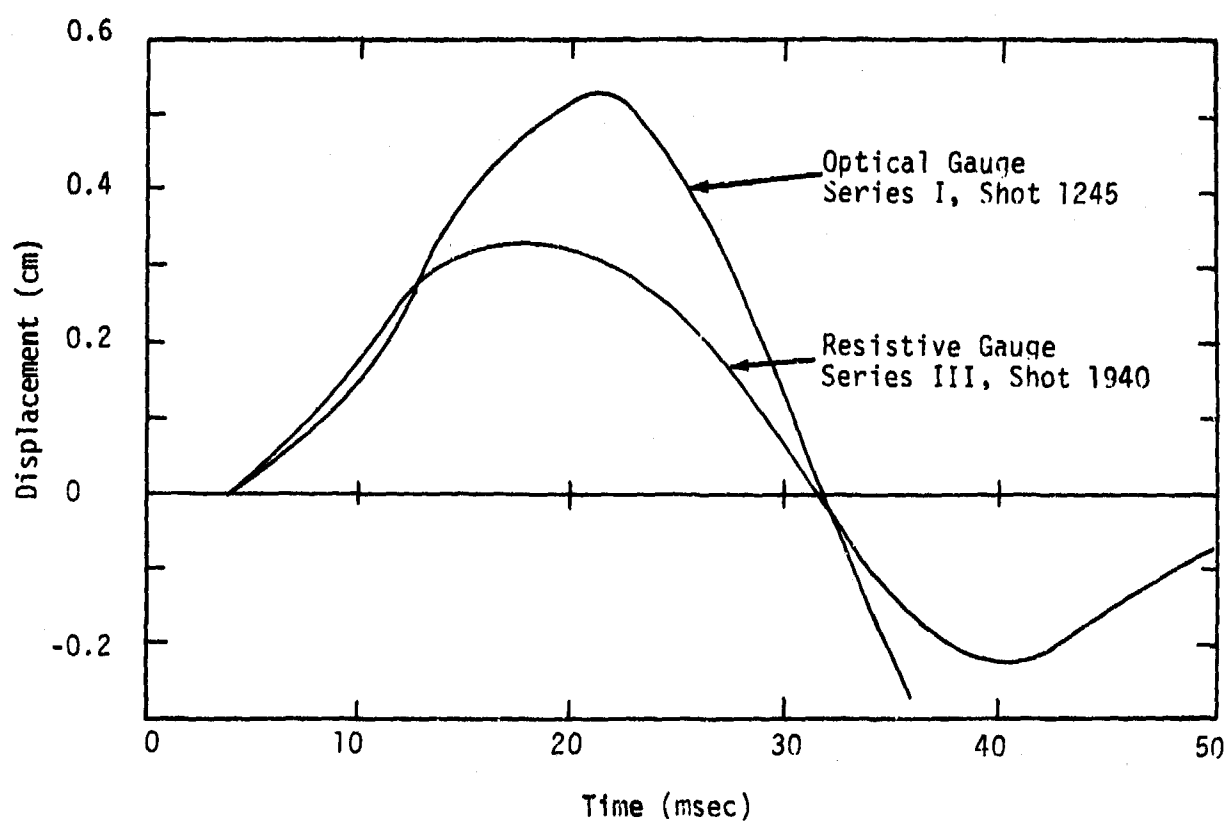


Figure 3.6 Drift Tube Displacement Data

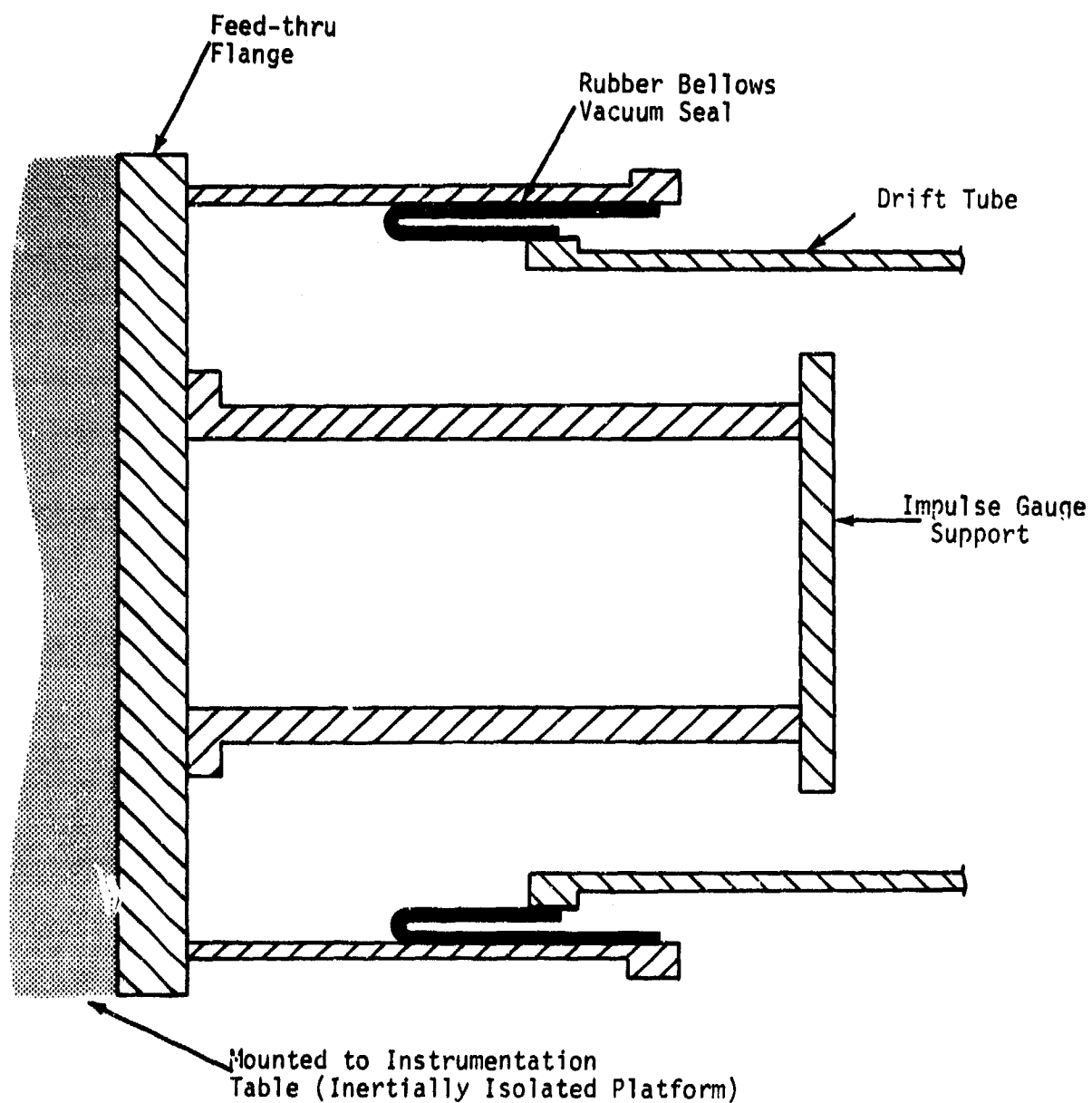


Figure 3.7 Shock Isolator

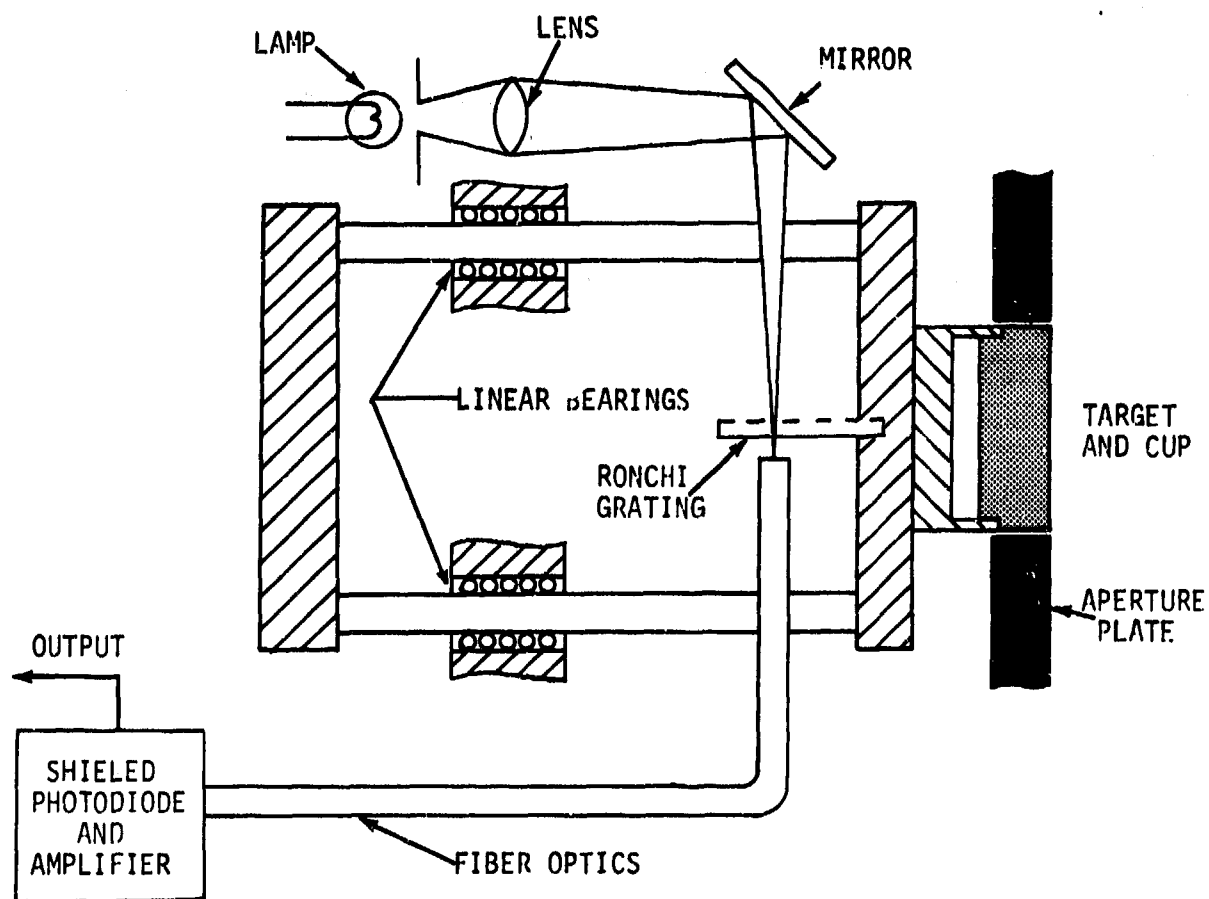


Figure 3.8 Impulse Gauge No. 1, 10-cm²

Parallel glass epoxy rods move in linear ball bushings. The motion is detected by modulating a light beam focused on the Ronchi ruling which is attached to the specimen carrier assembly. Detection of the modulation is made by a shielded photodiode and amplifier, which for this system were placed within the impulse gage support. Tests were performed which demonstrated that neither magnetic fields nor machine shock affected gage performance.

Test Series III was an opportunity to test a unique impulse gage configuration wherein two 5.1-cm^2 area specimens were exposed side-by-side in each shot. Figure 3.9 shows one half of this gage. It also used moving Ronchi rulings with dual photodiodes and amplifiers added to the support structure. An additional feature of this gage was the addition of peripheral total stopping calorimeter blocks, shown in Figure 3.10. This configuration allowed for an in situ diagnostical measurement on each data shot. Figure 3.11 displays representative data for this gage configuration.

The final gage design developed during this program was similar to Impulse Gage No. 1. For this third design, stainless steel rods replaced the glass epoxy rods to reduce vibration, and peripheral calorimetry completely surrounded the smaller 8.5-cm^2 specimen. The reduced specimen size was implemented to increase the fluence uniformity across the specimen surface and to bring the peripheral calorimetry as close as possible to the uniformly irradiated area. As is seen

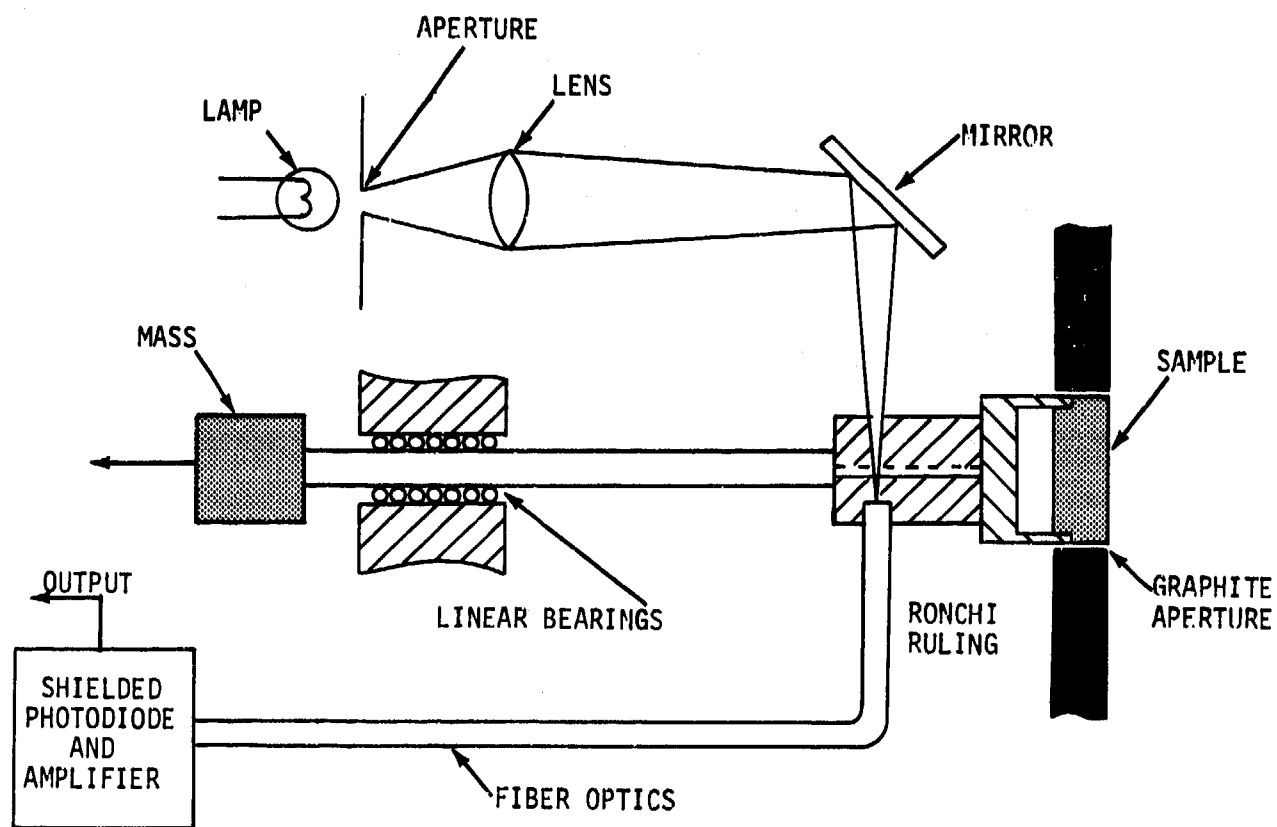


Figure 3.9 Impulse Gauge No. 2, Dual, 5.1-cm²

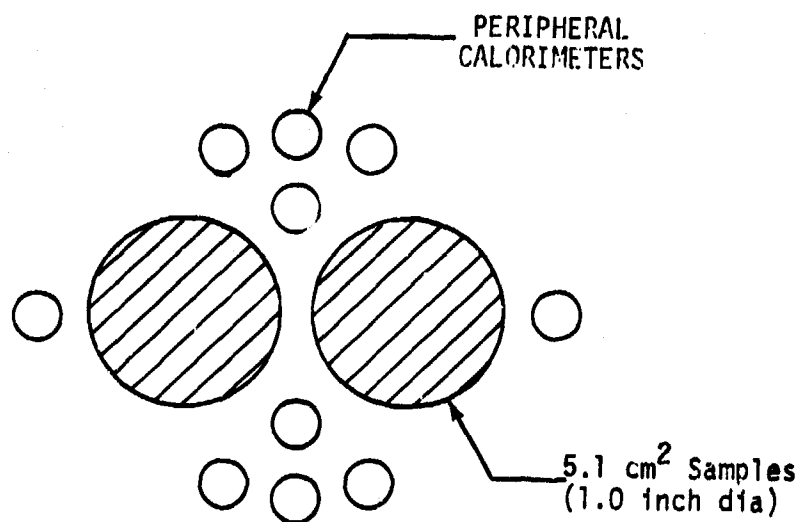


Figure 3.10 Peripheral Calorimetry Layout, Impulse Gauge No. 2

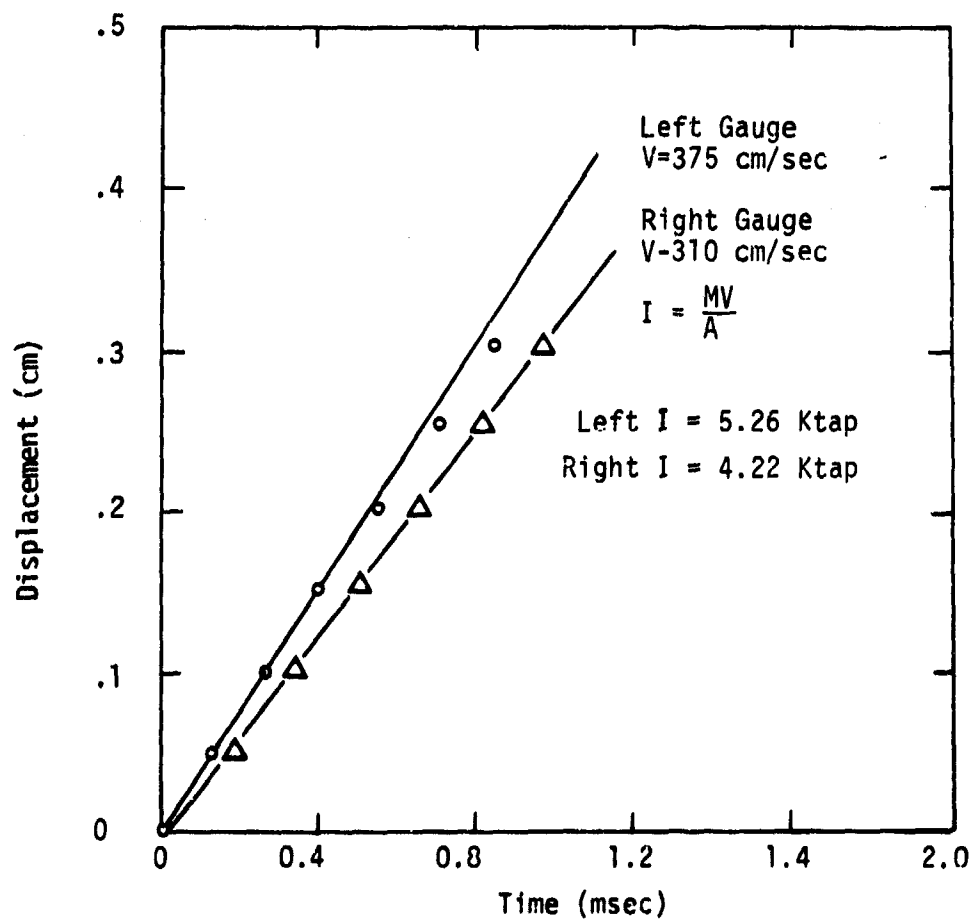
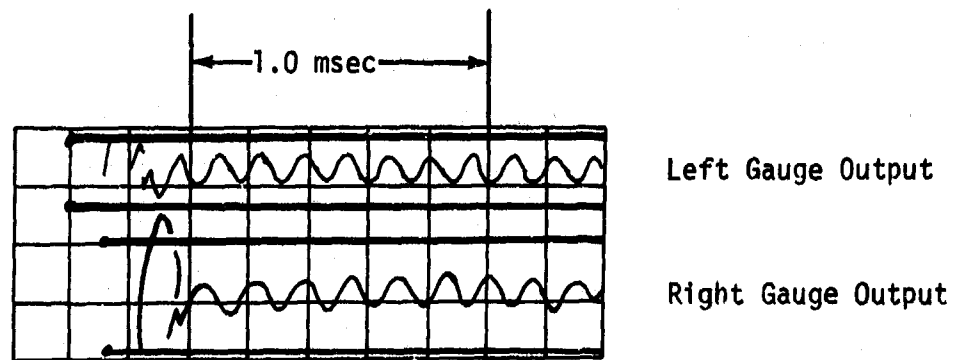


Figure 3.11 Representative Carbon Phenolic Data from Impulse Gauge No. 2

from Figure 3.12, access for an interferometer laser beam was provided by removing the impulse gage light source and the photodiode/amplifier from the gage assembly and using a fiber optic light guide to transport the light beam to the Ronchi ruling. The source and receiver of the beam were placed in a shielded area external to the drift chamber. In order to eliminate high volume apertures and lenses in this system, the light beam was modulated by the motion of one Ronchi ruling relative to a stationary one. A schematic of the peripheral calorimetry for this gage is shown in Figure 3.13, and a photograph of the entire assembly is shown in Figure 3.14.

Effects of anode debris impact on the impulse gage performance were also defined. In the pursuit of a more homogeneous radial electron fluence distribution, a carbon cloth scatterer was placed in the region of maximum magnetic beam compression (refer to Figure 3.1). The reason for placement of the scatterer in this region was that the electron angle induced by the magnetic field is at a maximum there, thus allowing the carbon cloth the greatest potential for radial scattering and effecting in-plane fluence homogeneity. Tests revealed that the carbon cloth also reduced the anode debris momentum which is a persistent error in impulse measurements in electron beam environments of this energy range. Table 3.2 shows the results of such tests. It appears that with the cloth in place, the momentum attributable to anode

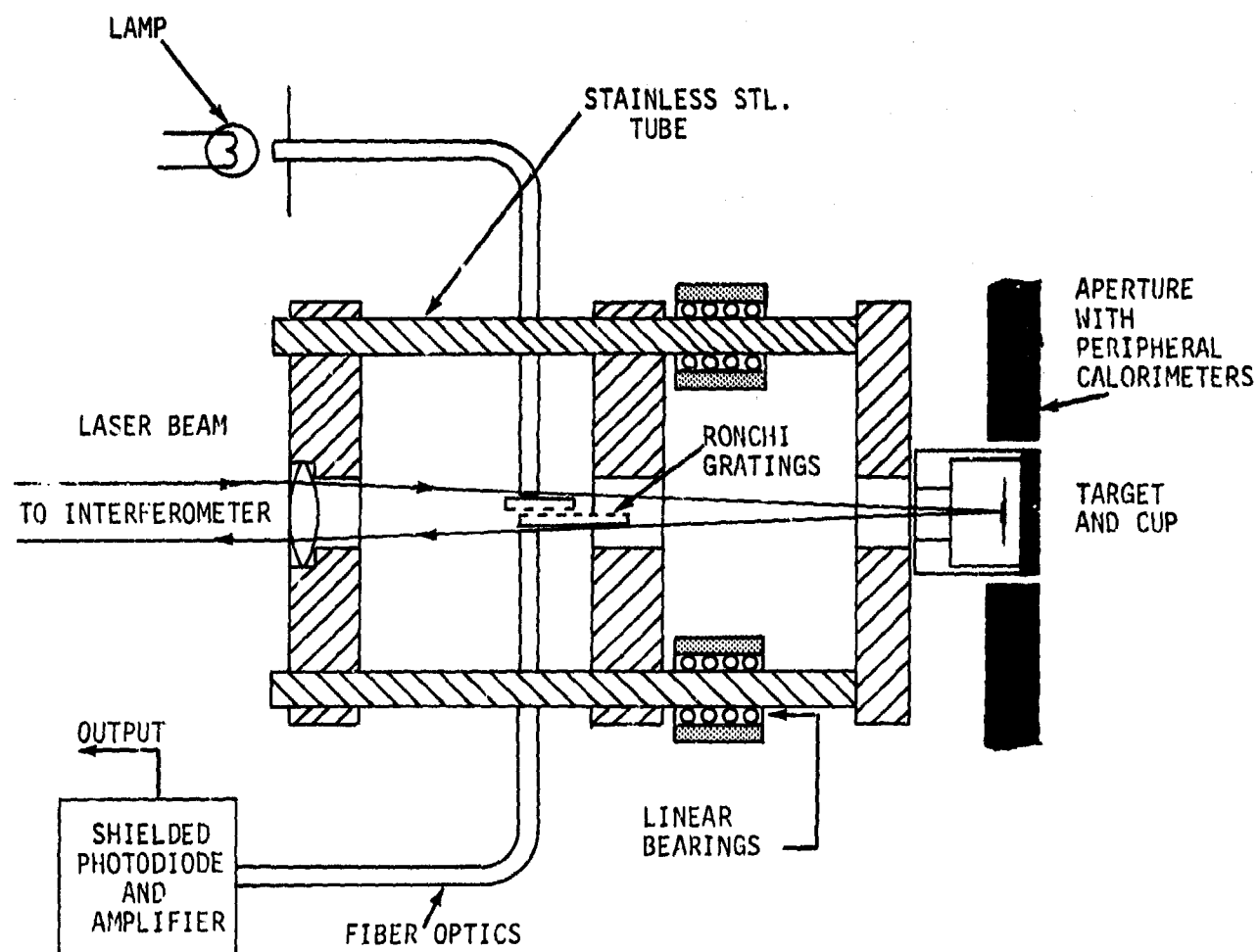


Figure 3.12 Impulse Gauge No. 3, 8.5-cm

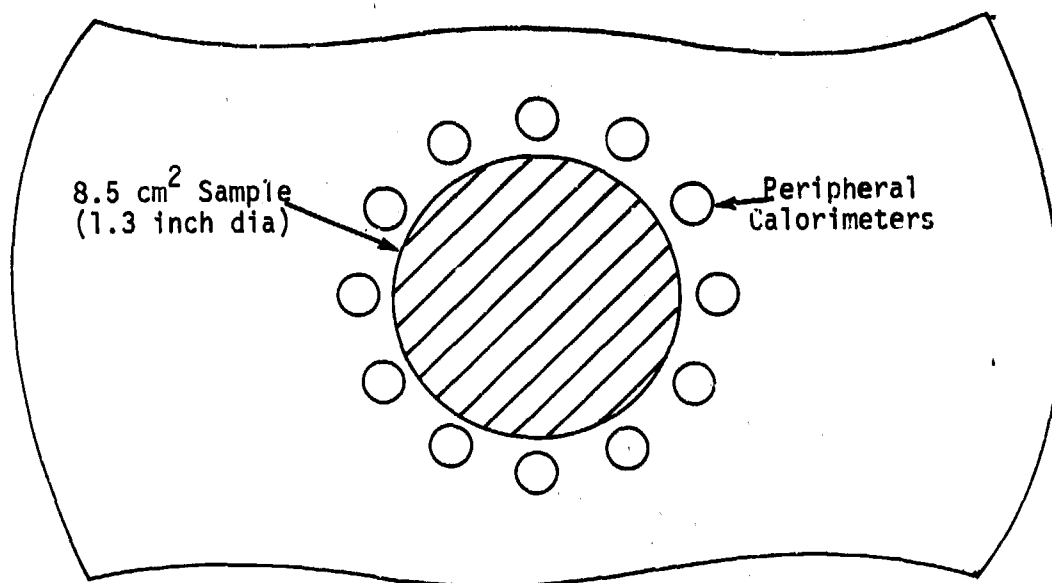


Figure 3.13 Peripheral Calorimetry Layout,
Impulse Gauge No. 3

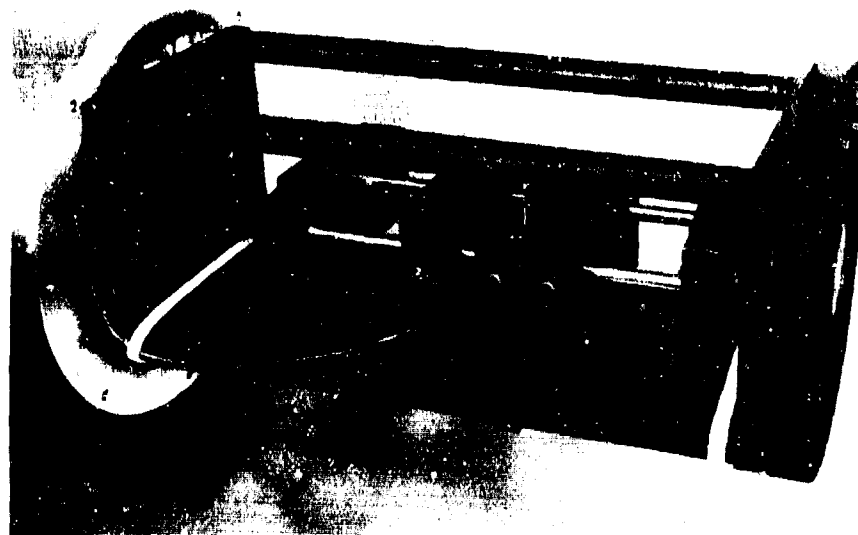


Figure 3.14 Impulse Gauge No. 3 with Peripheral Calorimeters and Shock Isolation Mount.

Table 3.2

ANODE DEBRIS DATA SUMMARY

Shot	Filter* ?	Gauge Type**	Distance from Anode (cm)	Gauge Area (cm ²)	Impulse (ktap)
1632	No	0	65	10	(0.06)
1646	No	0	65	10	(0.07)
1740	No	1	65	10	0.04
1829L	Yes	2	70	5	0.10
1829R	Yes	2	70	5	0.11
1841	Yes	2	65	5	0.09
2271	Yes	3	60	8.5	0.12
2296	Yes	3	60	8.5	0.13

Note: Anode is 1/4 mil mylar.

*0.025 gm/cm² graphite cloth.

**0, Passive indenter gauge.

1, See Figure 3.8.

2, See Figure 3.9.

3, See Figure 3.12.

debris is about 100-taps. This is the condition in which most of the specimens were exposed. It should be noted that this indicates that not only is the anode debris a very small uncertainty in the impulse measurements in the TWCP and 91-LD materials, but that the impulse gage is capable of resolving very low impulses.

3.3 INTERFEROMETER DEVELOPMENT

The interferometer device used on these tests was not developed under this program, but it was necessary to adapt an available interferometer with the Blackjack III machine. Measurements of displacement and velocity have been made for a number of years using this type of instrument.

Velocities of the mirrored rear surface of a reference material (either plexiglass or fused silica) were measured using the Corrales Applied Physics Company combined velocity and displacement laser interferometer. Velocities below about 0.1-mm/ μ s were measured with the displacement interferometer, while higher velocities were best resolved with the velocity mode. Resolution of often ambiguous velocity reversals was made using a quadrature system which provides two phase shifted interferometric signals. The photomultiplier detectors were located approximately 60-feet away in a shielded instrumentation room with the inteferometer beams being transported from the electron beam target area by mirrors.

Tests were conducted to assure that the pulsed magnetic field did not affect the helium-neon laser plasma tube and to verify the proper shielding of the photomultiplier tubes.

4.0 MATERIAL RESPONSE TESTING

The material response data were generated during two test series, designated:

Test Series V: May 1978

Test Series VI: July 1978

Impulse, Grüneisen and propagated stress-time data were obtained on the 91-LD Ironsides phenolic material, and on the "NHEP" Tape Wrapped Carbon Phenolic (TWCP) designated FM5822A. The details of these tests are documented in Volume IV; this section summarizes the results.

4.1 TEST MATRIX

The actual test sequence is given in Volume IV. It is important to mention that extensive beam diagnostical pulsing was performed to fully characterize the beam condition. These diagnostical shots were performed before, between, during and after material response shots. This includes the in situ calorimetry which was key to reducing the experimental uncertainties.

Table 4.1 summarizes the entire matrix, without regard to the time sequence. The measurement configurations are described in Section 4.2. Representative fluence mappings are shown in Figures 4.1, 4.2 and 4.3 for various anode-sample spacings.

4.2 SAMPLE CONFIGURATIONS

Four basic configurations were used as shown in Table 4.1, and illustrated in Figure 4.4. The attenuation

MATERIAL RESPONSE DATA

<u>Material</u>	<u>Measurement</u>	<u>Number of Shots</u>
FM5822A	Gruneisen	9
	Stress Attenuation	4
	Sublimation Energy	0
	Impulse	7
91-LD	Gruneisen	10
	Stress Attenuation	0
	Sublimation Energy	6
	Impulse	

BEAM CHARACTERIZATION

Fluence Mapping	58
-----------------	----

Table 4.1 Test Matrix

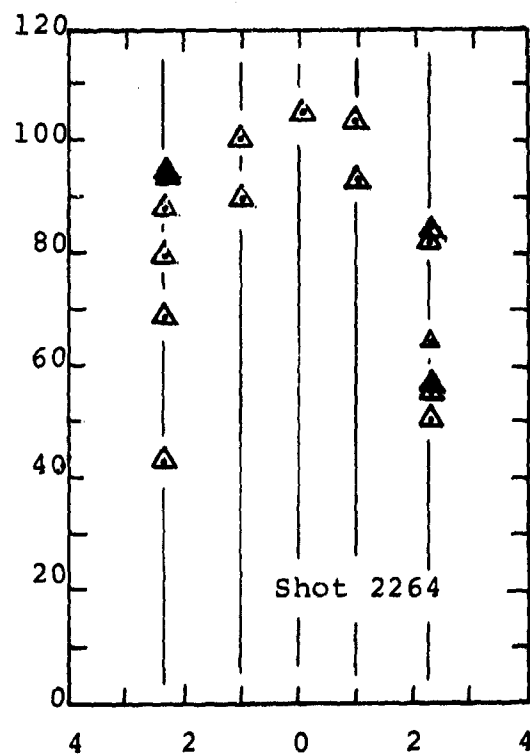
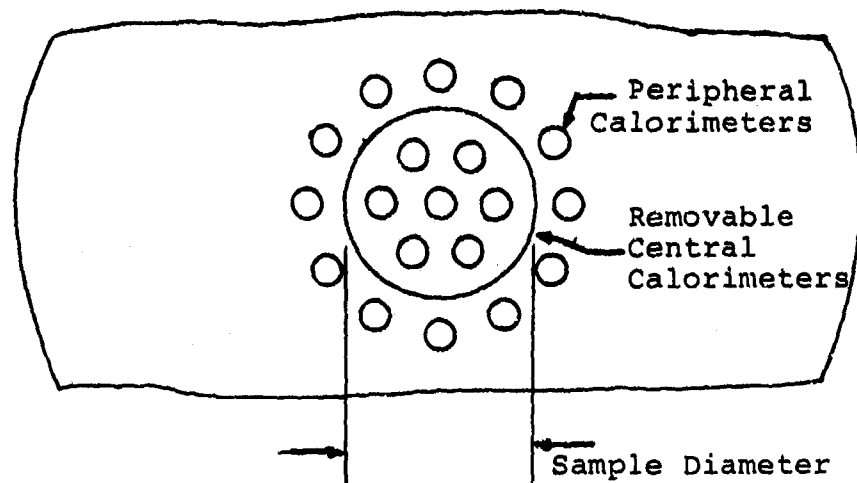


Figure 4.1 Representative Fluence Distribution at 60-cm.

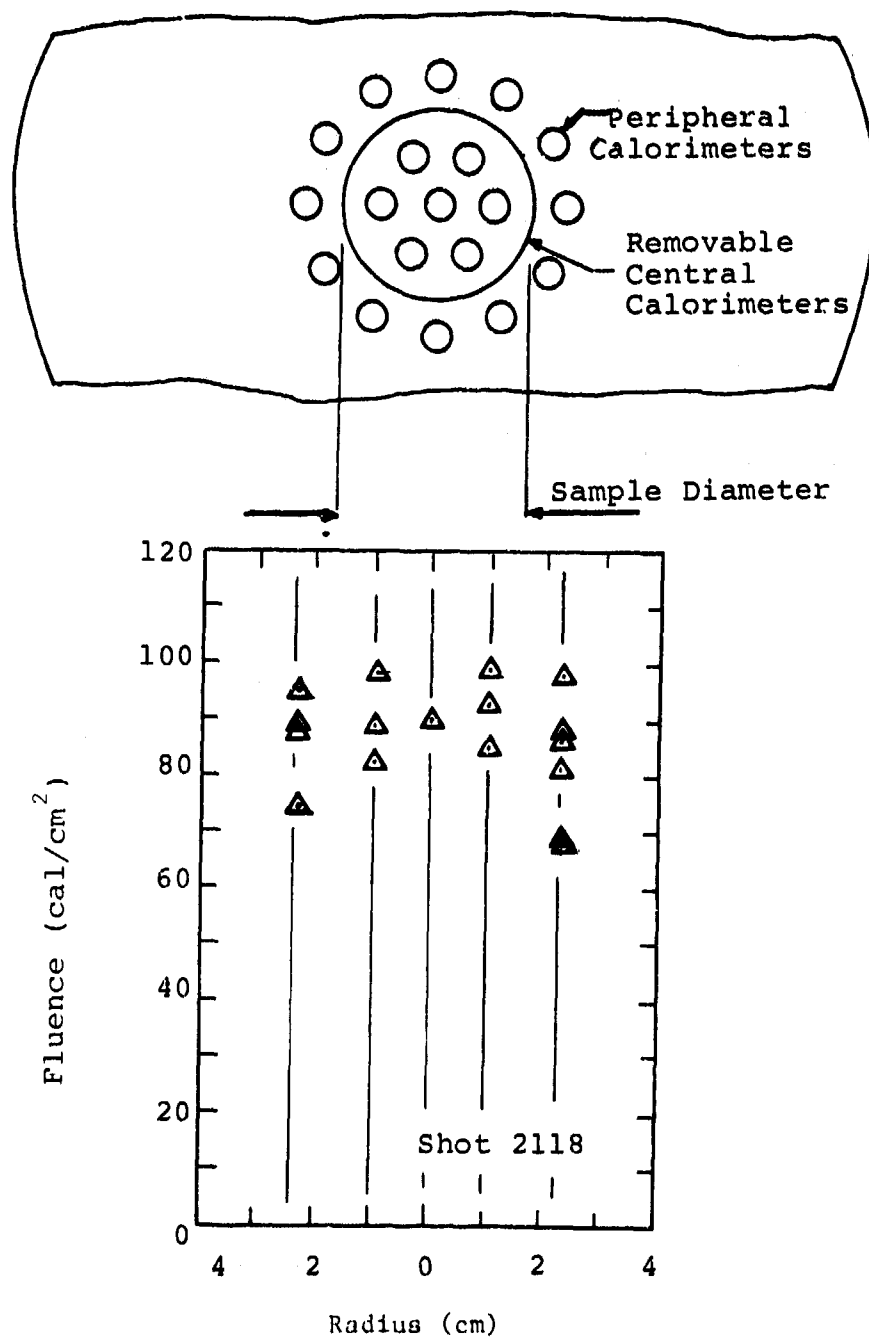


Figure 4.2 Representative Fluence Distribution at 64-cm.

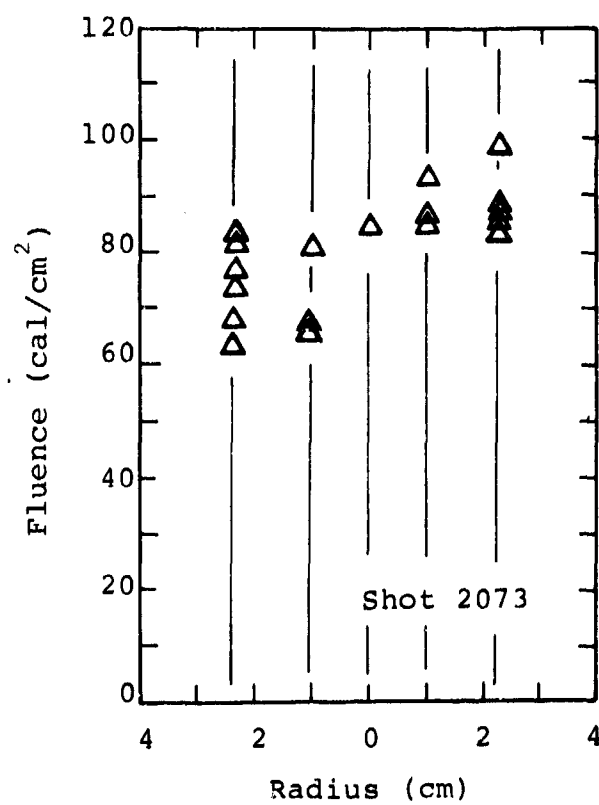
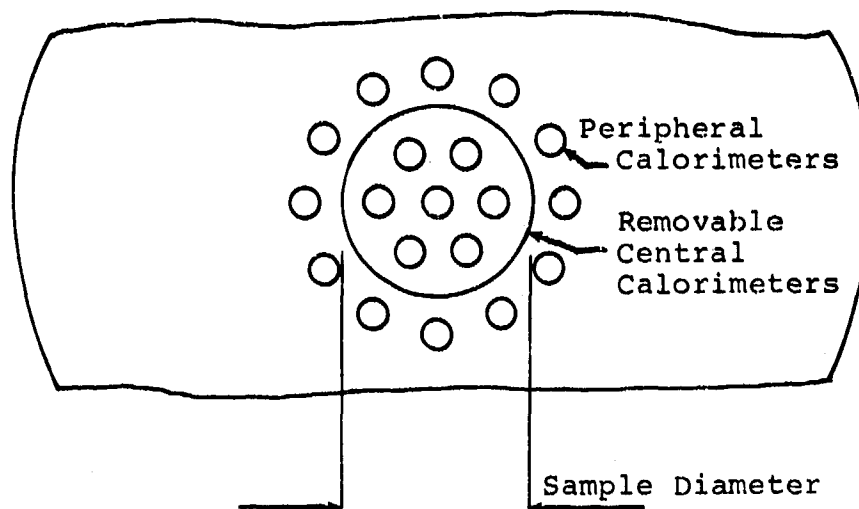


Figure 4.3 Representative Fluence Distribution at 68-cm.

configuration was designed to measure the stress wave attenuation through a thick piece of TWCP. These data have application in modelling the stress wave propagation through TWCP and provide the initial stress levels for wave propagation into a substructure.

The Grüneisen configuration used a thin sample of TWCP or phenolic to measure the stress generation as a function of deposited energy. To do this, sample thicknesses were chosen to be sufficiently thick to stop all the electrons and prevent deposition in the fused silica buffer. Stress wave attenuation is thereby minimized in the sample.

The impulse configuration was actually a dual measurement. The primary objective was to measure generated impulse as a function of deposited energy, but it was possible, through the use of Impulse Gage 3 to also measure rear surface particle velocity. This approach was desirable since the stress-time and impulse data on the same shot can be correlated. It is also a more efficient means of generating data, since two pieces of information result from one data shot.

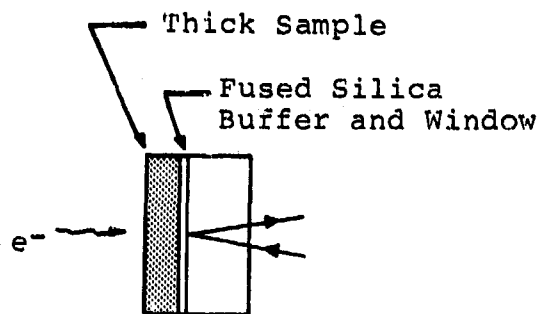
The fourth configuration, the final energy (E_g), used a thin sample with the idea of making an impulse measurement in a thin, uniformly heated sample. This technique was unsuccessful due to the epoxy bonding agent seeping through the graphite and generating a large stress, decoupling the graphite from the sample. This led to a meaningless impulse

measurement, and no stress measurement. Only a limited number of shots were attempted with this exploratory technique.

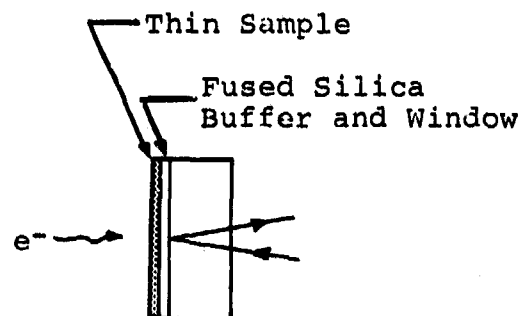
4.3 SUMMARY OF RESULTS

The particle velocity vs time data are shown in their entirety in Volume IV. Representative traces are shown to indicate the general response for the different materials and configurations. Figure 4.5 is a Grüneisen trace for TWCP and Figure 4.6 is a stress wave attenuation trace. Figure 4.7 is a Grüneisen trace for 91-LD phenolic.

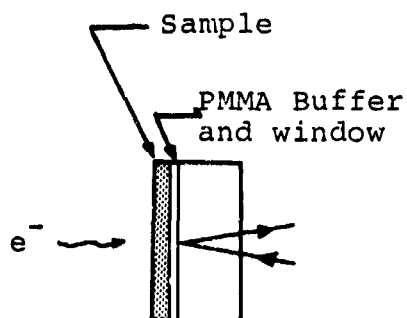
Impulse data are plotted in Figure 4.8 and 4.9 for the FM5822A TWCP and 91-LD phenolic respectively as a function of fluence.



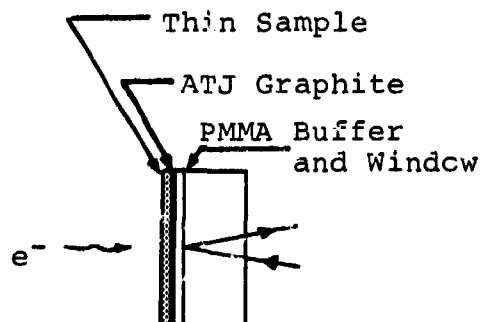
Attenuation Configuration
(particle velocity
measurement only)



Gruneisen Configuration
(particle velocity
measurement only)



Impulse Configuration
(particle velocity and
impulse measured)



E_s Configuration
(particle velocity and
impulse measured)

Figure 4.4 Test Configuration

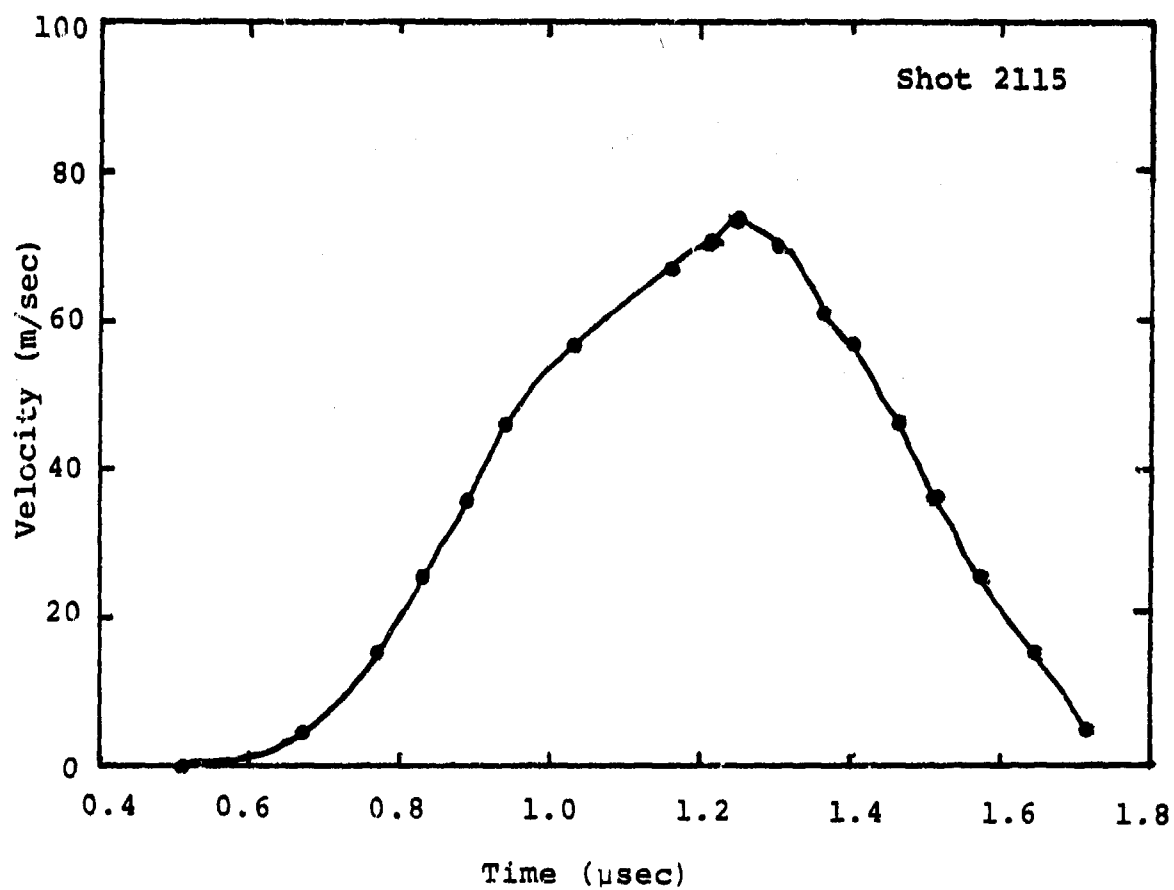


Figure 4.5 Particle Velocity Data for Shot 2115,
TWCP Grüneisen

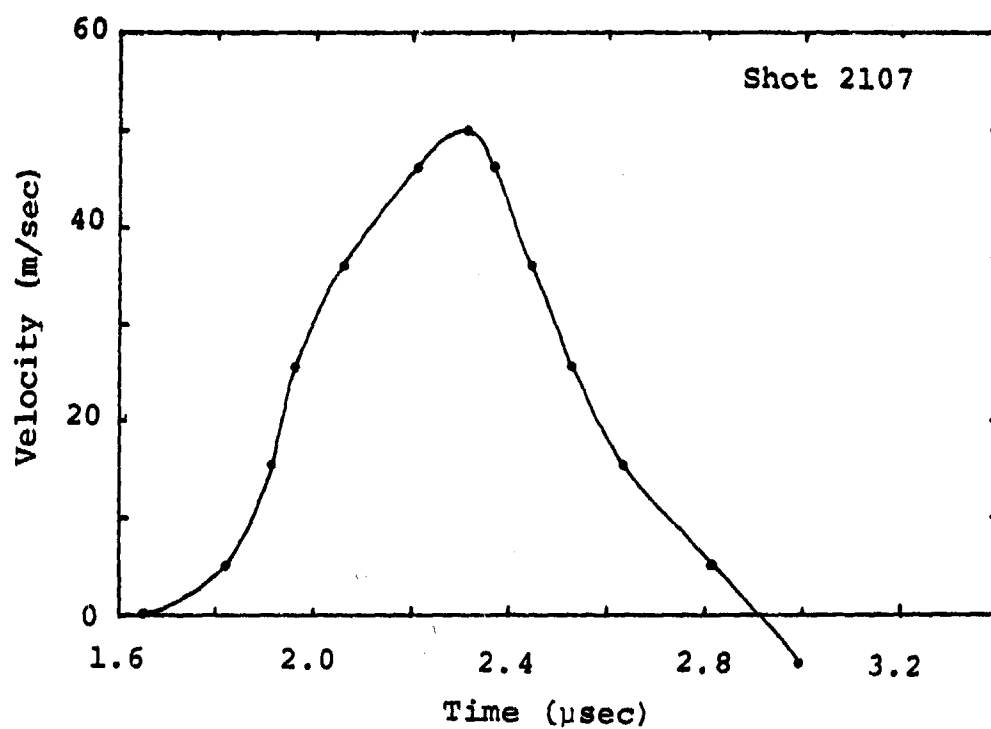


Figure 4.6 Particle Velocity Data for Shot 2107,
TWCP Attenuation

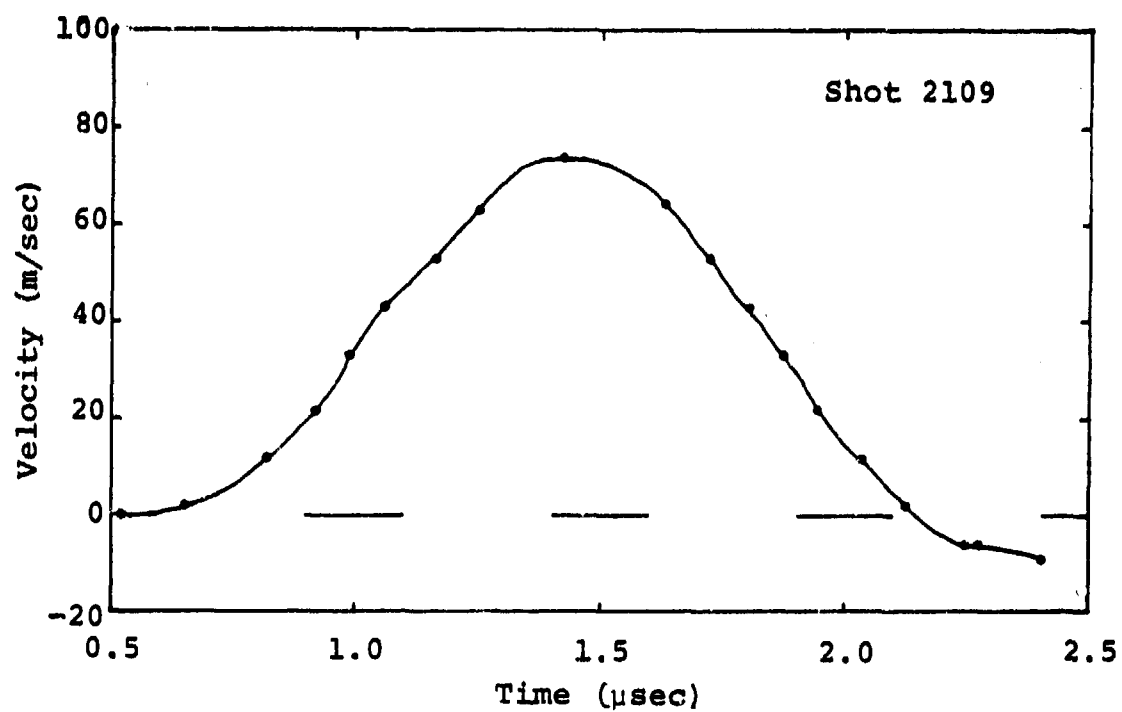


Figure 4.7 Particle Velocity Data for Shot 2109,
91-LD Phenolic Gruneisen

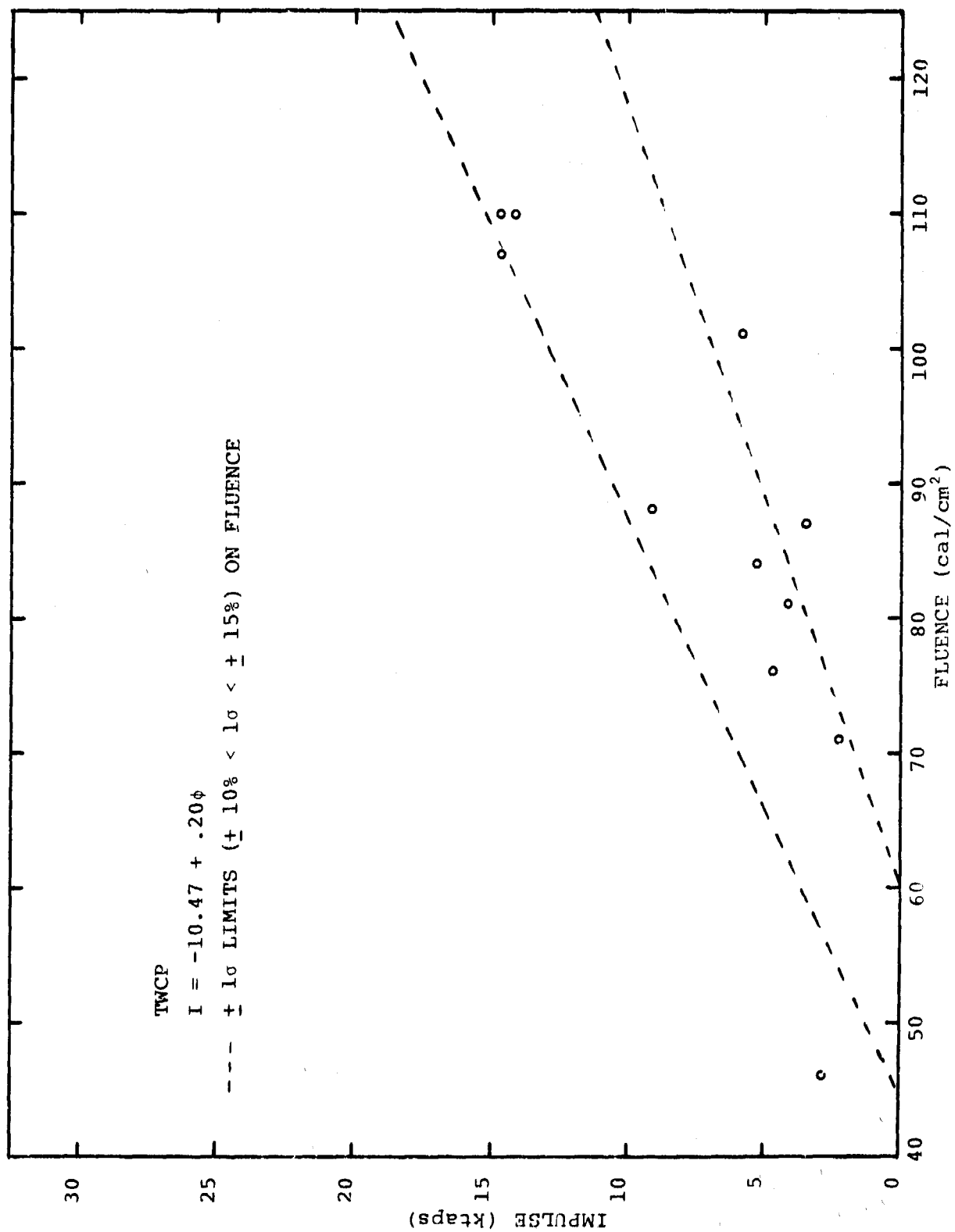


Figure 4.8 FM5822A TWCP Impulse Data

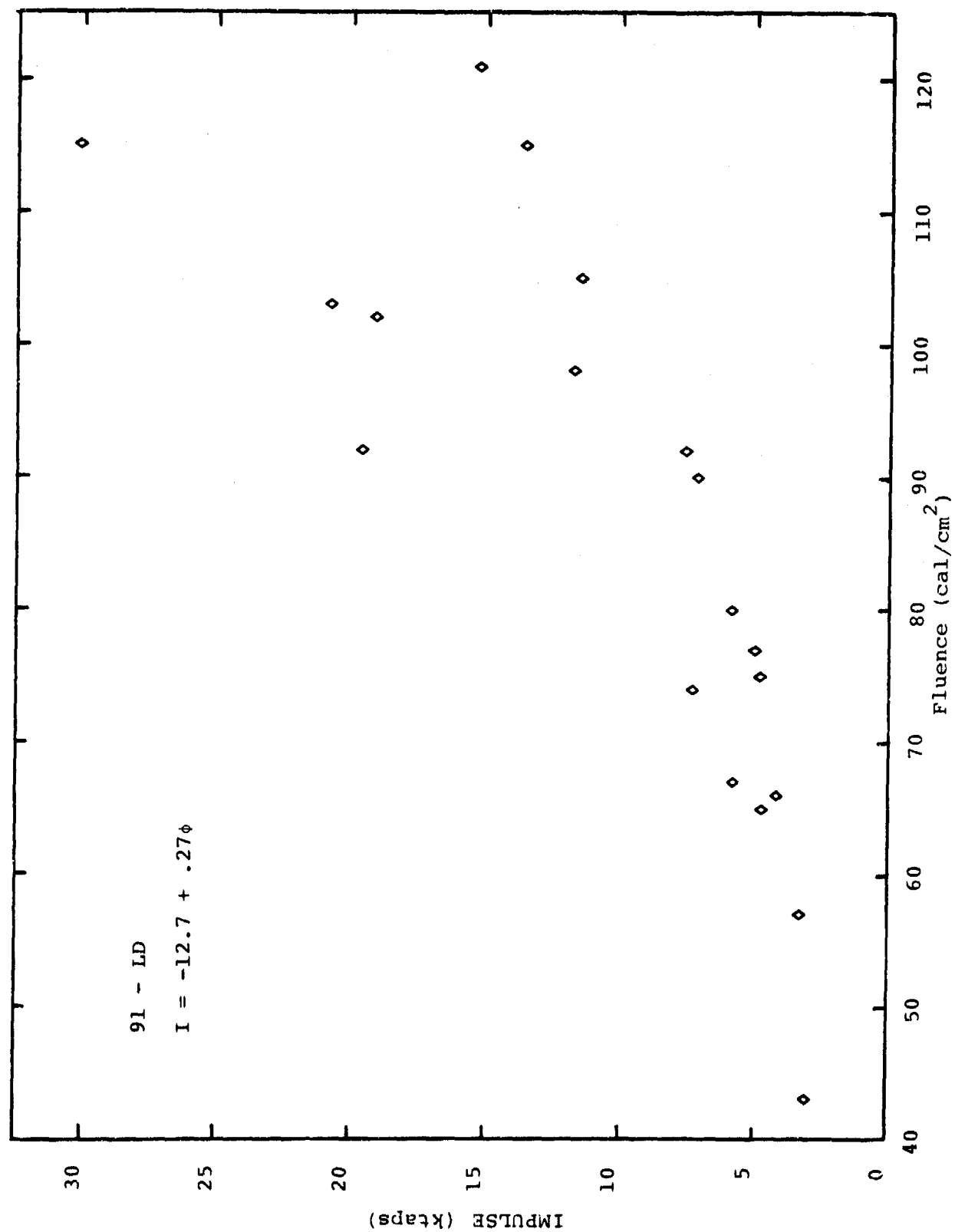


Figure 4.9 91-LD Phenolic Impulse Data

5.0 DATA ANALYSIS

Because the data obtained in this experimental program are being analyzed under the auspices of the "TWCP Correlation Program", Air Force Weapons Laboratory contract F29601-77-C-0076, a cooperative effort with DNA, a data analysis leading toward derivation of $E_g(E)$ and $\Gamma(E)$ has not been attempted in this report. However, some discussion of the data is appropriate since it is ultimately to be used within the framework of the NHEP Program. This discussion centers upon the impulse data that are presented in Volume IV.

5.1 SAMPLE CONFIGURATION

Four sample configurations were used to obtain impulse and stress generation data as shown in Figure 4.4. As discussed in Volume IV, bonding material soaking into the graphite invalidated impulse data obtained with the $E_g(E)$ configuration, and in one case for the Gruneisen configuration, it is recommended that they not be included in any data analyses.

5.2 ϕ_c/ϕ_p RATIO

A novel approach to diagnostics was attempted in these experiments in an effort to reduce experimental error, i.e., the use of peripheral calorimeters during data shots and the ϕ_c/ϕ_p correlative ratio. Referring to Figure 3.13, ϕ_p indicates the peripheral calorimeters that were in place during material response shots. ϕ_c refers to a central set

of sevel calorimeters shown in Figure 4.1 that were inserted in the sample area during diagnostical shots at a particular anode-sample spacing. The ratio of ϕ_c/ϕ_p , multiplied by the measured quantity ϕ_p on a material response data shot yields the fluence per unit area over the sample. In addition to these diagnostics, redundant pulsings were made on the same configuration in order to obtain a statistically valid data set. This approach was successful for beam diagnostics, although some anomalies in response data remain unexplained at this time. In Volume IV, Froula, et al, combine all data from Test Series V and VI which were performed in May and July of 1978. The assumption was that BJ III would perform the same for equivalent set-ups, even though separated in time. Table 5.1 indicates an alternative analysis of these diagnostical data. Note that it differs from the treatment of Froula, et al shown in Table 5.2 (reproduced from Volume IV) only in the ϕ_c/ϕ_p ratio for the smallest anode-cathode spacing which is where the separation of the May and July test series occurs. There are some other differences in how the alternative ratios were determined, but the final results are within the experimental error and are not significant.

Note, in Table 5.1, that the variation in fluence (peripheral) is on the order of $\pm 10\%$ to $\pm 15\%$ for May and $\pm 25\%$ for July, but by use of the ϕ_c/ϕ_p ratio, the uncertainties are dropped to $\pm 8\%$ or less for May and $\pm 16\%$

Table 5.1 ϕ_c/ϕ_p CORRELATION FACTORS REVISED

MAY TEST SERIES						
SHOT No.	DISTANCE TO ANODE (cm)	ϕ_c (cal/cm ²)	ϕ_p (cal/cm ²)	RATIO ϕ_c/ϕ_p	AVE. RATIO & % STANDARD DEVIATION	COMMENTS
2149	60	77	72	1.07	1.10 ± 8%	
2143	61	66	65	1.02		
2124	63	104	87	1.20		
2119	64	97	92	1.05	1.04 ± 7%	Shot 2116 not used. Appears anomalously low.
2118		92	83	1.11		
2116		29	32	.91		
2111		103	97	1.06		
2110		79	84	.94		
---	66					Not used. No data taken at this spacing.
2099	68	67	76	.88	.93 ± 5%	Shot 2092 not used. Appears anomalously low.
2097		62	69	.90		
2092		38	41	.93		
2089		79	83	.95		
2085		88	88	1.00		
2073		81	82	.99		
2070		79	85	.93		
2068		83	96	.86		
2063		71	77	.92		
2062		96	105	.91		
2061		59	64	.92		
---	70				1.34 ± 16%	Not used. No data taken at these spacings.
---	71					
---	72					

JULY TEST SERIES						
2291	60	112	101	1.11	1.34 ± 16%	
2283		69	57	1.21		
2281		60	57	1.05		
2278		98	81	1.21		
2275		94	67	1.40		
2270		106	65	1.63		
2267		57	55	1.04		
2264		95	72	1.32		
2260		56	42	1.33		
2244	61	104	64	1.63		
2243		132	90	1.47		
2252	62	124	90	1.38		
2250		78	65	1.20		
2249		126	73	1.73		

Table 5.2 SUMMARY OF FLUENCE CORRELATION FACTORS

<u>CAPCo ANALYSIS</u>			
Distance from Anode (cm)	No. of Data Shots	Average Ratio	Standard Deviation (%)
60-63	17	1.30	20
64-67	11	1.00	8
68-72	18	0.95	5
<u>ALTERNATIVE ANALYSIS</u>			
60-63	3	1.10	8
			Test Series V May 1978
60-63	14	1.34	16
			Test Series VI July 1978
64	5	1.04	7
68	10	.93	5

for July. The implication is that the use of peripheral in situ calorimetry results in a significant reduction in environmental uncertainties.

5.3 IMPULSE DATA

The correlation factors for ϕ_c/ϕ_p shown in Table 5.2 must be applied to all data to arrive at fluences on sample. The product of ϕ_p and ϕ_c/ϕ_p on a given data shot yields this value. The data are tabulated in Volume IV using the CAPCo correlation factors. They are plotted for TWCP and phenolic in Figures 5.1 and 5.2 respectively using the alternative correlation factors from Table 5.2.

Figure 4.8, the TWCP impulse data, also shows the $\pm 1\sigma$ limits on fluence which corresponds to about $\pm 15\%$, twice as large as the ϕ_c/ϕ_p ratio uncertainties (no TWCP impulse data were taken in test Series VI in July 1978). This tends to indicate that other uncertainties contribute to the overall uncertainty. Possible examples are erratic hot spots in the beam, poor gage performance, variable sample preparation and material property variations. For instance, if the 8% ϕ_c/ϕ_p ratio is used along with a gage uncertainty of 5%, and a representative 5% material property variability, then the total error is about 11%. The only numbers that can be verified are the ϕ_c/ϕ_p ratio and the impulse gage error, so these numbers only indicate how various error contributions can come into play and affect the final answer. It is fair

to say that it is through the use of ϕ_c/ϕ_p and the resulting fluence uncertainty reduction that leads to other error sources becoming significant. Figure 4.9, the 91-LD phenolic impulse data, does not lend itself to such an analysis. In fact, there seem to be two distinct and separate data trends, one of high impulse and one of low. Various analyses have been attempted, including solid spall on the front face by various mechanisms, and none can explain the impulse data above 20-ktaps. While a least squares fit equation is shown on the figure, it includes all the data as plotted. Any attempt to plot 1 σ bounds exceeds $\pm 25\%$. Clearly if the > 20-ktaps data were eliminated, the data group very nicely, but no reason exists for eliminating these data, including:

- Sample appearance post test
- Gage performance
- Spectral shifts
- Recording instrumentation settings
- Front surface mass removal.

This leaves as possible explanation:

- Anomalous beam hot spot
- Material variability
- Unknown phenomena.

It is not possible to identify the reason for this behavior within the context of this program. It is expected that it will be resolved in the "TWCP Correlation Program" wherein a variety of TWCP materials are being evaluated and the data can be cross-correlated to determine if the high impulse

values shown here are valid.

6.0 CONCLUSIONS

There are four primary conclusions to be derived from these six test series:

- 1) In situ diagnostics significantly reduce the environmental uncertainties;
- 2) Redundant data points statistically aid in reducing experimental uncertainties;
- 3) When an electron beam machine is performing erratically, as in Test Series VI, significant uncertainties result, regardless of the diagnostics. Nevertheless, conclusions 1 and 2 still apply.
- 4) The Maxwell Laboratory's Blackjack III electron beam machine has been successfully established as a viable nuclear weapons effects test facility.

The material response and environment diagnostical instrumentation developed for this program were an integral part of the uncertainty reduction. These techniques are available for general use and will be applied by ETI to a series of experiments to be performed on other materials at the Physics International OWL II facility, Maxwell Laboratory's BJ III and the Boeing Radiation Laboratory FX-75.

The final judgment as to the validity and value of the data will come from the NHEP Program, and specifically the "TWCP Correlation Program" being performed by M. Rosen of Effects Technology, Inc. for the Air Force Weapons Laboratory and the Defense Nuclear Agency.

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2. Young, T.S.T. and Spence, P., "Model of Magnetic Compression of Relativistic Electron Beams", Applied Physics Letters, Vol. 29, No. 8, 15 October 76, pp. 464-466.

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